ASSESSING DESIGN AND FUNDING METHODS OF WATER INFRASTRUCTURE FOR SASKATCHEWAN FIRST NATIONS

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Abstract

Many water systems on First Nations in Saskatchewan are at risk of not being able to consistently meet water quality guidelines, which negatively impacts human health. It was the goal of my thesis to assess design and funding methods for water infrastructure projects on First Nations. It was important that this research was informed by community values and priorities gained from discussions with Elders, interviews with water treatment officers, and activities with elementary and high school students.

A scoping review looked for existing literature on water infrastructure projects that involved the community in the design process, termed 'co-design'. Of 1,551 articles searched, only 13 were found using the search terms (and synonyms): "water", "co-design", "Indigenous communities", "infrastructure", and "Canada". A common definition of co-design and clear process is required to trend towards community informed design. Co-design as a process for water infrastructure in Indigenous communities encompasses the cultural, traditional, and spiritual values associated with water from the community's worldview along with the environmental and technical conditions from an engineering standpoint. The increased involvement for this process requires extra funding, which is difficult in communities that are already restricted by rigid funding frameworks.

Communities prefer a centralized system (piped water) to reduce the likelihood of contamination and water quantity rationing. The preference for a centralized system is prevented by a funding formula that does not provide the higher capital expense of this infrastructure. However, the formula can be expanded beyond capital investment and regular operation and maintenance to include costs associated with human health. The installation of both decentralized and centralized systems were quoted and compared for an example community of 100 homes (500 people). The approximate capital cost of a centralized system and decentralized system were found to be $ 3,512,000 and $ 1,365,000, respectively. However, the extra costs associated with the decentralized system were $ 570,000 per year, which covers the greater capital investment for a centralized system in under 5 years. The provision of safe drinking water for human health justifies a greater capital investment on its own, but the inclusion of other variables in the funding formula suggests that it is economically feasible as well.

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List of Abbreviations

AANDC: Aboriginal and Northern Developments Canada

COE: College of Engineering

CRM: Cost Reference Manual

EC: Environment Canada

FHQDev: File Hills Qu'Appelle Developments

FHQTC: File Hills Qu'Appelle Tribal Council

FSIN: Federation of Sovereign Indigenous Nations

HC: Health Canada

IBROM: Integrated Biological and Reverse Osmosis Membrane

INAC: Indigenous and Northern Affairs Canada

MTA: Municipal Type Agreement

RBC: Royal Bank of Canada

SDWFNA: Safe Drinking Water for First Nations Act

SPH: School of Public Health

SWHRT: Safe Water for Health Research Team

THMs: Trihalomethanes

WTPOs: Water Treatment Plant Operators

Chapter 1: Introduction and Background

1.1 Introduction

Indigenous communities including First Nations, Metis, and Inuit peoples in Canada struggle to maintain a consistent supply of safe drinking water although it has been made a priority area of investment by the Government of Canada. It is widely understood by the various stakeholders that this issue is not due entirely to a lack of technical understanding, but it is rather a failure of water system management and lack of understanding of community contexts and cultural priorities. Thus, the goal of my thesis research was to investigate these barriers to access to safe drinking water. Specific concerns from communities were presented to the research team by partners at the Federation of Sovereign Indigenous Nations (FSIN). This led into a process that was initiated and informed throughout by community values. It was stated that communities were frustrated by a lack of communication in the design and funding processes leaving them with failing infrastructure. This research was made possible by funding provided by the Royal Bank of Canada's (RBC) Blue Water Project. This funding formed the start of my thesis research which allowed our research team to spend time in First Nations communities to interact with Elders, students, parents, teachers, and water treatment plant operators (WTPOs). Our research team was able to provide science presentations and demonstrations for elementary and high school students. These visits helped to inform the resulting research by providing for a better understanding of the unique social values of each of the communities. It should be noted that the RBC funding was attached to a First Nations-specific project with communities based in Saskatchewan, therefore this thesis will generally use First Nations rather than Indigenous nomenclature.

It is becoming understood amongst the various stakeholders that infrastructure projects on First Nations would benefit by including community members in the design process. This process of co-designed infrastructure would help to combine the worldviews from industry/government/academia/others and the individual First Nations to create an outcome that satisfies community needs technically, culturally, and spiritually. For this process to be adopted, professionals would need a clear definition and procedure for implementation of a co-designed project. There is currently a lack of literature on this subject (as presented later in this thesis) and the existing literature is not consistent in the level of involvement and methodology. It is acknowledged that a co-designed project is likely to be more expensive and time intensive than a conventional design project, especially in terms of capital costs. This increased cost is an issue currently for First Nations because of the rigid government funding frameworks in place for capital projects.

Beyond the lack of community consultation and tangible outcomes for previous and current research and capital projects, we have learned that the communities are frustrated with the lack of funding needed to address critical needs. This leaves communities with water infrastructure that is often inadequate to meet quantity demands and is constantly at risk of causing human health due to quality concerns. Currently, the typical level of funding provided in Saskatchewan affords communities with a decentralized low-density housing arrangement with cisterns at each home with trucked water delivery. There is opportunity for contamination of the water in these systems at multiple points in the delivery process and the use of cisterns forces households to ration their water supply for fear of running out before the next delivery due to small storage volumes. Thus, the method in which water distributions systems are funded needs to be expanded to include quantifiable, easily monetized impacts beyond only considering the initial capital investment. This expanded analysis will help communities to justify a greater capital expense in exchange for savings on mitigated impacts in the future. Essentially, water infrastructure projects need to consider both capital and operation and maintenance costs (which will be expanded herein) to help meet the needs of all Canadian Indigenous communities.

1.2 Background

Human health in First Nations communities has historically been negatively impacted by poor access to drinking water (Waldner et al., 2017). Although the issue has been recognized, communities still struggle for solutions to drinking water challenges that must address technical, social, and political aspects specific to each community. The responsibility for providing water infrastructure on First Nations is shared by Aboriginal Affairs and Northern Development Canada (AANDC), Health Canada (HC), and Environment Canada (EC) (Bradford et al., 2016). This structure of multiple Federal departments complicates the progress of water infrastructure projects on First Nations. These departments typically provide 80% of infrastructure costs with the individual nation Chief and Council being responsible for 20% of the infrastructure costs, as well as the operation and maintenance (Bradford et al., 2016). To First Nations, water is seen as a spiritual resource beyond its utility as a physical necessity making the collection of this 20% difficult given water is distributed without charge to the community. It is important to understand this perspective when considering legislation or infrastructure. In 2012, the Federal government introduced bill S-8, the Safe Drinking Water for First Nations Act (SDWFNA), to help address shortfalls of legislation (Morrison, 2015). However, this bill has been criticized for its lack of community consultation and resulting deficiency of cultural and traditional contexts (Black and McBean, 2017).

The challenges with access to needed funding directly impacts the quality of water treatment and distribution leading to the creation of health challenges in communities. In Canada, it is more likely for a First Nations community to experience waterborne illnesses and to have at risk water infrastructure as compared to the national average (Boyd, 2006). Overall, recent studies have shown that 30% of water systems on First Nation communities are described as high risk (Black and McBean, 2017). A high-risk water system, as defined by Burnside (2011), is one that has major deficiencies that could impact the health of a community. There are a wide range of health issues that are prevalent on First Nations as a result of high-risk water systems including gastrointestinal illnesses, skin disease, and kidney disease. Additionally, limited or restricted access to safe drinking water can also have an impact on mental health by causing anxiety and stress (Bradford et al., 2016).

There are several components of a community's water distribution system that can lead to the creation of high risk to human health. For example, even if a community has an effective water treatment plant, there can still be individual homes without safe water. The majority of First Nations in Saskatchewan are on a decentralized water distribution system (Burnside, 2011). A decentralized system has different stages involved in getting water from the treatment plant to the household taps that can result in contamination. Water is delivered by a truck to a holding tank (cistern) at individual homes. Contamination can occur during the filling of the truck or the filling of the households' holding tanks. Also, if the cistern is not properly maintained or replaced at the end of its lifecycle, it can fail in keeping out pathogens, fecal matter, chemicals, and other contaminants. Currently, the amount of funding for a First Nations water infrastructure projects is determined based on the lowest lifecycle cost alternative with the formula used for determining this option only considering the capital cost of construction. This formula will be updated in this thesis to include operation and maintenance and 'some' of the social costs of a decentralized system that may not be functioning well. For example, a social cost could be the value of lost time having to boil water or driving to a different community to see doctors because of an illness contracted from lack of safe drinking water. The caveat 'some' is used as the current social costs should only be considered as an initial group that will be expanded over time once other social costs become clearer.

1.3 Review of Drinking Water Systems in Saskatchewan

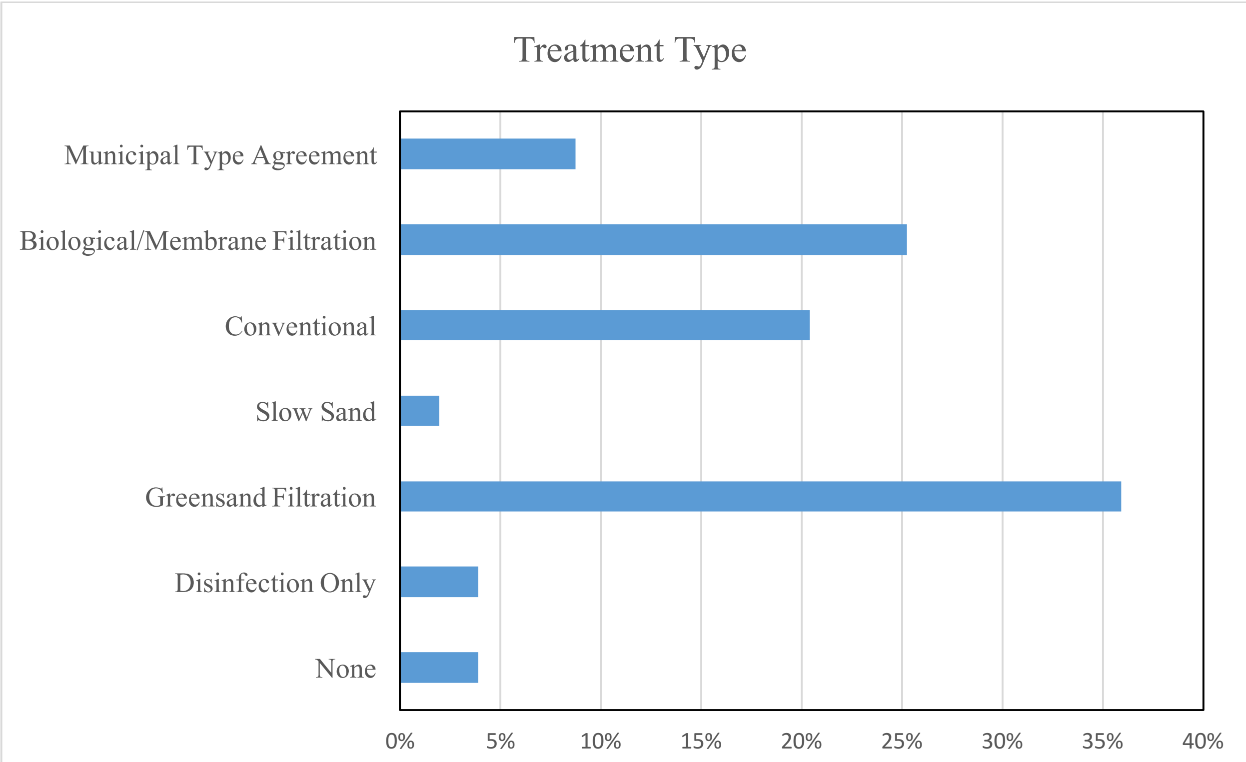
In 2011, the Department of Indian and Northern Affairs Canada (INAC) in the Federal government released a report created by Burnside (2011) assessing drinking water systems on First Nations in Canada. Other than this report, historically there is a lack of literature available auditing water systems on First Nations. As part of this study, there is regional information specific to Saskatchewan that provides a valuable overview of water infrastructure statistics for the 103 water systems servicing 68 First Nations. (Burnside, 2011). This report suggests that 25% of water systems are in a condition likely to cause health concerns and drinking water advisories which require immediate corrective action to meet regulations. This compares to 30% of water systems operating with minor deficiencies and that are consistently meeting water quality guidelines (Burnside, 2011). Despite needed water quality, another concern is water quantity with 69% of water systems having exceeded 75% of their design capacity (Burnside, 2011). Water quantity is a concern given the increase in First Nations' community populations. Statistics Canada reported that the Indigenous population in Canada grew 20% from 2006 to 2011 compared to 5% for the rest of the Canadian population during the same period (STATCAN, 2011). Further, more than one half of the Indigenous population is living on reserve (STATCAN, 2011). It is therefore important that the water treatment systems are suited for expansion to accommodate increasing demand over time.

1.3.1 Saskatchewan Water Sources and Treatability

Firstly, there are 9 communities that have municipal type agreements (MTA) with other municipalities to provide drinking water; thus, these communities are excluded in the current discussion. In the remaining communities, there are 70 groundwater systems, 7 groundwater under influence from surface water, and 17 surface water systems servicing 14,278 homes in total (Burnside, 2011). Typically, groundwater water supplies are of a higher initial quality and are therefore simpler and easier to treat than surface waters (Reynolds and Richards, 1982). Surface water quality is impacted by high variations due to seasonality making them more difficult and complicated to treat. However, in Saskatchewan overall nearly 50% of people rely on groundwater as their drinking water source and 10-15 percent of those have reported increased levels of arsenic and uranium (Thirunavukkarasu et al., 2014). The prevalence of these minerals, as well as high levels of iron and manganese, make the treatment process difficult and expensive for the First Nations that have a groundwater source. In general, both groundwater and surface water sourced drinking water treatment can be a challenging task needing multiple treatment processes and technologies.

1.3.2 Drinking Water Treatment Plants

When the Burnside report was published in 2011, there were 21 conventional treatment plants, 37 greensand filtration plants, and 27 membrane filtration systems on First Nations in Saskatchewan. In addition, most of the membrane systems were likely to include either a biological or greensand pre-filter making them a more complex system. A summary of treatment types is shown in Figure 1.1 and Table 1.1 that provide a brief summary of some of the advantages and disadvantages of the types of water treatment systems used on Saskatchewan First Nations.



(Burnside, 2011)

Figure 1.1: Summary of Treatment Types on Saskatchewan First Nations

Table 1.1: Summary of Advantages and Disadvantages of Common Treatment Methods

Treatment Method	Advantages	Disadvantages
Conventional Treatment	▪ Low cost treatment of surface water ▪ High capacity	▪ Not well suited for treatment of groundwater ▪ Large footprint
Manganese Greensand Filtration	▪ Effective iron and manganese removal ▪ Easy operation	▪ High chemical usage ▪ Lower removal of arsenic at high concentrations
Biological Filtration	▪ Low chemical usage ▪ Easy operation ▪ Effective removal of iron, manganese, and arsenic	▪ High capital cost
Membrane Filtration	▪ High removal efficiency ▪ Small footprint	▪ High capital, operation and maintenance cost ▪ Energy intensive ▪ Low capacity and expensive expansion

(Shirazi et al., 2010; Massé et al., 2011; Halle, 2009; Benner et al., 2013; Simpson, 2008; Thirunavukkarasu et al., 2014)

1.3.2.1 Conventional Treatment

A conventional water treatment system generally consists of a series of physical chemical processes such as coagulation and flocculation, sedimentation, filtration, adsorption and disinfection to remove turbidity, pathogens, and organic matter from water (Crittenden et al., 2005). This definition can also be expanded to include membrane processes like reverse osmosis (Garfi et al., 2016). Each system process is made up of a combination of physical, chemical, and/or biological treatment methods. The use and sequence of the methods is determined by the quality of untreated water and the desired quality of the finished product (Tchobanoglous, 1987).

For example, a typical treatment of surface water could involve the following sequence of processes: screening, coagulation, flocculation, sedimentation, filtration, and disinfection. Screening is done to prevent large organic matter such as branches, vegetation, and/or algae from entering the treatment plant. Coagulation and flocculation are used to help to remove non-settling colloidal particles (Reynolds and Richards, 1982). A coagulating chemical such as aluminum or iron salt is added to destabilize the colloids and create a mass that will settle. The precipitated aggregates and suspended solid particles are then filtered out in a rapid sand pressure filter (Tchobanoglous, 1987). Flocculation and sedimentation processes are more common in the treatment of surface water and, therefore, are not used on First Nations with groundwater sources.

A typical treatment process train for groundwater containing iron and manganese for drinking water could involve: oxidation, aeration, filtration, and disinfection (Tchobanoglous, 1987). The dissolved iron will be in a ferrous state and must be oxidized to its ferric state and precipitate as ferric oxide (Reynolds and Richards, 1982). Similarly, manganese will be oxidized into a state that precipitates (Tchobanoglous, 1987). An oxidizing agent such as air, chlorine, oxygen, or potassium permanganate is used to oxidize iron and manganese into precipitates that can be filtered out (Reynolds and Richards, 1982). This process requires a detention tank and an appropriate retention time to allow for the oxidation process to occur. Adaptations can be made to this basic process to remove other soluble minerals such as arsenic from groundwater. The most typical technology on First Nations is the use of greensand filter media, often supplemented with downstream membrane ‘polishing’.

1.3.2.2 Greensand Filtration

Saskatchewan’s groundwater is often high in iron, and 10-15% of communities that rely on groundwater also report levels of arsenic, uranium, and selenium (Thirunavukkarasu et al., 2014). Manganese greensand filtration is designed to remove iron, but the adsorbed iron also removes arsenic. Iron is removed as it is precipitated by a redox reaction with the sand coating (Hiiob, 2012). The overall treatment process is similar to the conventional treatment of groundwater but involves a pressure filter with a specialized greensand filter media. The precipitation of manganese and iron requires pre-treatment with an oxidant such as chlorine or potassium permanganate (Thirunavukkarasu et al., 2014). The oxidation changes the solubility of various forms of iron and manganese allowing them to precipitate which can be mechanically removed by filtration. For decades, manganese greensand filtration has been successful in the removal of iron and manganese from groundwater but can fail to achieve significant removal if source water concentrations are very high (Qin, 2008). In situations where the levels of iron are very high, a conventional greensand filter is not always appropriate and requires greater pre-treatment (Lessard, 2000).

1.3.2.3 Biological Filtration

Biofiltration is a process in which an otherwise conventional granular filter is designed to remove not only fine particulates but also dissolved organic compounds through microbial degradation (Halle, 2009). The filter media provides a matrix for biological growth to treat organic compounds by microbial degradation (Basu, 2015). This process has been used for centuries as the slow sand filtration process allows the development of a biofilm. However, more sophisticated media and cultures have been developed (Chaudhary 2003) making the biological filter process a successful method for removing organic matter and pollutants that are often difficult for conventional treatment (Simpson, 2008).

Conventional treatment without biological matter requires greater chemical input. Chemical disinfection using chlorine combined with residual organic matter can create harmful compounds, such as trihalomethanes (THMs). Biological matter in the granular filter media is able to access compounds entrapped in pore spaces. The reduction of residual organic matter allows for more chlorine for residual disinfection (Simpson, 2008).

Biological filters have the capability to remove other micropollutants along with the removal of organic compounds for the production of safe drinking water. The treatment of micropollutants, such as pesticides and pharmaceuticals, has been economically challenging for conventional treatment systems. In contrast, using biological cultures in an activated carbon matrix has shown potential as a more cost-effective treatment option for these contaminants. (Benner et al., 2013)

1.3.2.4 Membrane Filtration

Membrane processes such as ultrafiltration or reverse osmosis remove contaminants by forcing water through a selectively permeable or semipermeable membrane that has a pore size on the nanoscale (Yoon et al., 2009). Semipermeable membranes can have pore diameters as small as 3 angstroms (1 angstrom = 10^{-10} m) (Tchobanoglous, 1987). The pore size being this small allows dissolved solids to be removed from water passing through it. Removal by membrane filtration for water treatment requires a hydrostatic pressure gradient as the driving force for mass transfer. Nanofiltration, ultrafiltration, and reverse osmosis are similar in that they all have a semipermeable membrane driven by hydrostatic pressure (Reynolds and Richards, 1982). However, reverse osmosis uses a reverse osmotic action as well as a filtering action. Water will diffuse from the side of the membrane with high chemical potential (low concentration) to the side of lower chemical potential (higher concentration). If the system has a finite volume, the water will flow until the pressure difference balances with the chemical potential difference. This pressure is called osmotic pressure (Reynolds and Richards, 1982). When an hydrostatic pressure gradient is applied opposite and greater than the osmotic pressure, the water will flow from the area of low chemical potential to the area of high chemical potential, called reverse osmosis (Tchobonglous, 1987). This allows particles smaller than the pore size to remain adsorbed on the intake side.

Membrane filter treatment technology is widely used because of its removal efficiency and small footprint (Mierzwa et al., 2012; Chew, 2016). However, these systems are expensive to operate and maintain due to fouling of the membrane requiring cleaning or replacement (Shirazi et al., 2010; Massé et al., 2011). Fouling of membranes increases costs so there is often a pre-treatment filter to remove particulates (Halle, 2009).

1.3.3 Drinking Water Distribution Systems

Of the 14,278 homes on First Nations in Saskatchewan, approximately 75% of these are on a centralized system and the remaining 25% are serviced by a decentralized system. A centralized system is a pressurized, piped distribution network centred around the water treatment plant. These are commonly used for residences near the water treatment plant and become less common the further away as the population density decreases. In general, a typical pressure pipe system becomes expensive to service low density community layouts. However, a low pressure or low diameter piping network can be used for rural homes as a centralized system. Decentralized water distribution is a system of individual wells and cisterns at each home. The household cisterns are filled on a schedule by a water delivery truck that is filled at the water treatment plant. Advantages and disadvantages of each type of distribution system are listed below:

- Decentralized Distribution
    - Advantages:
        - These systems require less capital investment than a piped network.
        - Replacement of assets can occur independently.
    - Disadvantages:
        - There are multiple points for contamination of drinking water in a cistern.
        - Household water usage is limited by the cistern's capacity.
        - Cisterns must be inspected and cleaned, which increases operation and maintenance costs.
- Centralized Distribution
    - Advantages:
        - Operation and maintenance is less expensive and requires less involvement compared to a decentralized system.
        - Contamination is reduced because of the closed system.
    - Disadvantages:
        - There is a high capital expense especially as housing density decreases.
        - A failure in the system can disrupt service for many users.

1.4 Thesis Overview

The issues investigated in this research were presented by the FSIN. Specifically, surrounding water distribution systems and how the capital cost for construction is funded. They were interested in what the actual cost to the community amounted to when considering the illness from using contaminated cisterns. They also discussed the difficulty with research and infrastructure projects not including the community, which creates distrust and contributes to the failure of the water infrastructure. This problem identification resulted in the following research questions:

- What is the current state of literature for the collaborative design processes of water infrastructure projects on Indigenous communities in Canada?

It was recognized that communities desire a level of involvement in water infrastructure design processes that ensures their priorities are met. A common well-defined process that incorporates community values would create consistency and promote long-term success of projects.

- What is the true cost of decentralized water distribution systems on First Nations in Saskatchewan?

The contamination from decentralized systems creates distrust in water quality in communities. If the health impacts are quantified economically the safer alternative of piped distribution could be justified when considering a life cycle cost.

While addressing these questions, the research aimed to be inclusive and provide tangible benefits to the community in exchange for their time and insight. This objective was met by a program of engagement with First Nations that was referred to as the RBC project because of its funding source.

The RBC work did not contribute explicitly to the body of research in my thesis; however, the experience and exposure to the First Nations' communities was vital to the success of the body of research in my thesis. The RBC project and its importance are discussed in the engagement with First Nations section. This experience informed the scope of my research that resulted in two publications. Modified versions of the publications below make up the body of my thesis in Chapters 2 and 3.

Bradford, Lori E. A., **Tim Vogel**, Karl-Erich Lindenschmidt, Kerry McPhedran, Graham E. H. Strickert, Terrence A. Fonstad, and Lalita A. Bharadwaj. 2018. **"Co-design of water services and infrastructure for Indigenous Canada: A scoping review."** *FACETS* 3 (1):487-511. doi: 10.1139/facets-2017-0124.

Vogel, Timothy M., Rebecca Zagozewski, Terry Fonstad, and Kerry McPhedran. 2018. **"Assessment of Costs of Centralized and Decentralized Water Systems on First Nation Communities."** *CSCE Annual Conference.* Fredericton: Canadian Society of Civil Engineering.

1.4.1 Chapter 2

This Chapter is a modified version of a research paper created with the School of Public Health at the University of Saskatchewan. Its goal was to identify the level of literature on the topic of co-design in water infrastructure. My role was to identify the literature, analyze the research types and methods, discuss the trends and themes and identify gaps in the literature. Dr. Lori Bradford and I were the main co-authors of this publication; Dr. Bradford accepts the use of this manuscript as part of my thesis.

There is a trend in design methods for the process to be more inclusive of all stakeholders. The term co-design refers to engagement of stakeholders in the design process on some level from consultation to inclusion at every stage. For infrastructure projects this could mean the results consider other worldviews in the approach to design and incorporate cultural and traditional priorities in the finished product. Chapter 2 involved the search for well-defined examples of what this process could look like in Canada and to make suggestions on where research efforts should be focussed to grow this trend and inform the industry.

1.4.2 Chapter 3

This chapter was produced and published, with myself as the primary author, as a conference proceeding for the Canadian Society of Civil Engineering 2018 Annual Conference. The objective of this research was to assess the funding elements and frameworks for drinking water distribution systems on Saskatchewan First Nations.

Water distribution systems on Saskatchewan First Nations are failing to consistently provide safe drinking water to all households. Communities are trending away from decentralized water systems and prefer centralized piped distribution. The limitation for the transition from decentralized to centralized is the great capital cost required in low density community layouts. The current method for funding water distribution systems on First Nations in Canada is limited to the capital construction cost. Chapter 3 takes a different approach to considering design alternatives by expanding the scope of cost to include some health and other maintenance costs.

1.4.3 Chapter 4

The objective of Chapter 4 is to combine the RBC work with the two previous chapters to summarize outcomes. The significance of the overall body of this research is discussed and a forecast is provided on where this research could go and the possible avenues for future work.

1.5 Engagement with First Nations

1.5.1 Introduction

My research was funded by the Blue Water Project presented by the Royal Bank of Canada (RBC). The stated goal of the Blue Water project is to fund projects that focus on sustainability and water resource management (RBC, 2017). Our project was a collaboration between the University of Saskatchewan College of Engineering (COE), School of Public Health (SPH) File Hills Qu'Appelle Tribal Council (FHQTC), and File Hills Qu'Appelle Developments (FHQDev). This funding was used for community engagement visits involving science demonstrations for elementary and high school students and their teachers; discussions with Elders, parents, and family members; and interviews with water treatment plant operators (WTPOs). It should be noted that the RBC work did not provide specific outcomes for my thesis, but the experience taught me valuable lessons that could not have been learned readily by other methods. It was valuable in providing me a background and understanding into community dynamics, concerns, and values. Without it my research would not have been able to adequately address issues that these communities are facing.

1.5.2 Objectives

The goal was to engage communities to learn about their relationship and understanding of water as both a physical and spiritual resource. This included issues that communities face accessing safe drinking water. The intention of this knowledge gathering was to inform my thesis research and provide valuable outcomes that could be used in the future by the participating communities. The community gained science education for the schools and we as researchers gained insight for publications and presentations.

1.5.3 Method

The COE team partnered with FHQTC for the community visits. The team was made up of three College of Engineering professors (Dr. Kerry McPhedran, Dr. Sarah Gauthier, and Dr. Duncan Cree), the College of Engineering Indigenous Initiatives Coordinator (Matthew Dunn), Research Officer (Rebecca Zagozewski) from the School of Public Health, and three Graduate Students (Tim Vogel, Connor Theoret, and Maggie Norris). This resulted in six community visits with presentations and activities at each community's school as summarized in Table 1.2. Classroom demonstrations were led by the COE as part of a collaboration between the RBC project and the COE Indigenous Initiatives outreach. Matthew Dunn provided a presentation on examples of Indigenous Engineering and led an activity building a boat or bridge to cross a body of water. The boat or bridge was tested on its ability to hold weight (pennies) while maintaining structural integrity. The COE faculty gave a presentation on water quality and treatment methods and led an activity that had students build a water filter. The water filters were tested on their ability to clean 'dirty' water and the turbidity of filtered water was measured. Students were also tasked with creating their own water filters and writing down on post-it notes their understanding of water resources and the issues with water in their community.

Table 1.2: Summary of Community Visits

Date	Community	Grades	Number of Students	Participants
Nov. 21, 2016	Muscowpetung	5-8	20	Students and Elders
Nov. 30, 2016	Peepeekisis	8-10	35	Students and Elders
May 15, 2017	Standing Buffalo	5-6	15	Students and Elders
May 19, 2017	Carry the Kettle	10-12	40	Students and Elders
Jun. 12, 2017	Pasqua	5-6	20	Students and Elders
Jun. 15, 2017	Piapot	5-6	25	Students

Interviews with the WTPOs were conducted at each community with questions included in Appendix A. Please note that all interviews and community outreach activities were done with ethics approval from the University of Saskatchewan (BEH 16-436). The School of Public Health (SPH) researcher Rebecca Zagozewski led the interviews with WTPOs and Elders given her previous experience conducting similar interviews with other Indigenous communities in Saskatchewan. Further, the interview format followed was based on a previously successful checklist of interview questions used in other communities. It should be noted that this form was deviated from as the interviews progressed as the WTPOs and Elders were free to speak about whatever topic they wished and often the formal interview process had to be abandoned.

The students and other participants were asked to complete a post-it note exercise discussing the importance and value of water. This exercise had the participants write down water issues in their community, what water meant to them, and why it was important to protect water resources. Using the words from the students' post-it note exercise, a word cloud was generated using Zygomatic's worldcloud generator to learn the community's values regarding water and what concerns are emerging. Similarly, quotations from Elders and WTPOs have been used in academic presentations to show what the priorities are. Common themes were extracted and used to focus research efforts for my thesis project.

1.5.4 Outcomes

The important results of the RBC project were the relationships that were built and the qualitative insights regarding water on Saskatchewan First Nations. The summaries of classroom exercises, workshops and interviews directed the research. Common themes of distrust with the water systems arose such as cisterns are not trusted to contain safe water and residents do not use them for drinking water. WTPOs and Elders expressed a shortfall in funding for capital construction, operation and maintenance of water systems on various levels. As well, participants recognized a lack of proper consultation and communication. For example, WTPOs are typically not included on project management teams although they are most knowledgeable in regards to the drinking water treatment for their community. It was noted that there were few tangible outcomes for communities that have been involved in research projects previously.

My thesis drew from the sentiments of the community by investigating consultation on design projects and funding for water systems. Chapter 2 is a review of design methods and their level of involvement with the communities they are designing for. Chapter 3 covers the current approach to funding water infrastructure on First Nations to identify issues and shortfalls that impact communities. These chapters will be presented at the end of this current introductory chapter.

The insight and understanding gained from the community visits directly impacted the body of research in Chapters 2 and 3. In Chapter 2 a proposed definition of "co-design" is presented. This was influenced by the community visits by incorporating the inclusion of spiritual and traditional values as requirements for the process. From interviews with WTPOs, I learned the importance that their presence would have if they were included on project teams. It is then proposed that basic consultation is not enough for a truly collaborative process and suggests that the inclusion of WTPOs would be beneficial to project success. In Chapter 3, the social indicators added to the funding formula came from discussions with stakeholders during the community visits. I learned how it was not only the sick party that is affected when illnesses occur, but also their caregivers who are required to take time off to care for their sick loved ones, thus increasing the costs associated with illnesses. WTPOs discussed how water delivery trucks were travelling almost continuously on the community road network leading to increased deterioration of the community's roads. The inclusion of the increased road maintenance to the funding formula was a large factor in the additional annual costs associated with a decentralized system. Overall, the community visits not only taught me specifics related to my research, but it taught me alternate ways of viewing problems that will change how I approach research and professional projects.

1.5.4.1 School Visits

Classrooms were visited in partnership with the College of Engineering's outreach initiatives. Schools were provided with science presentations and demonstrations, lunch and prizes. A word cloud was generated, using an online tool (wordclouds.com), based on the words used by students when describing water, what it meant to them and what its importance was in their lives (Figure 1.2).

Figure 1.2: Word cloud generated from student understanding of water

The students showed an understanding of how important water is and how connected they are to it. They often referenced pollution, illness, drinking, swimming and fishing as connected to water. These issues are becoming more prevalent and the students have heard stories and are familiar with how water, and their relationship with it, has changed across generations.

My thesis did not explicitly incorporate these outcomes, but it was important for the research to give something back to the communities through these science demonstrations. These insights were the justification of need for the research papers produced in my thesis.

1.5.4.2 Summary of Elder group discussion

Community Elders were present at most of the classroom visits and one Elder discussion group was held. The Elders were asked to talk about the cultural importance of water and the issues that they have seen develop over the years. Table 1.3 provides quotations from these meetings expressing issues about water quality, water quantity, delivery methods and communication. There is a particular distrust of cistern water quality given they did not know what may be in the cistern (contamination) and mentioned that cleaning was financially constrained and not always completed when it should have been (even after boil water advisories). Water delivery from truck to cistern typically occurs once a week and, especially for large households, it is difficult to make the low quantity of water last for the week. Additionally, if water does run out the family must pay for a new delivery, which can become very expensive. These issues were echoed in most of the interviews with WTPOs. As well, the delivery is dependent on the conditions of the roads. For example, during extreme weather the roads may be inaccessible meaning that people are without water and connected sewage service.

People do not trust the capabilities of the water treatment plant when it is frequently starting and stopping due to (and during) drinking water advisories. There are concerns about contamination of the river from farming practices and upstream users. The water testing results are not presented to the public, so Elders are often looking for the results and have no way to find out if the water is safe at that time.

Table 1.3: Themes and Quotations from Elder Discussions

Themes	Quotes
Water Quality and Quantity	"We're stuck with what they let go in Regina, Moose Jaw, those places that come down that Qu'Appelle River." "It impacts our Elders here. Like a lot of them can't go and get water. It's a problem that they run out of water. But you need that water. Like a lot of us—I think all of us—we haul our water, our drinking water. We don't drink out of the tap." (Female Elder)
Health Impacts	"White scales, like…it makes you itchy. Your skin is itchy." "And a lot of these cisterns, too. You never know what you've got in there. Dead mice and it's very unhealthy. I'm scared to look in there sometime. I don't want to look in there."
Communication/Consultation	"So there's usually a concern about these studies that they keep doing. But what's the end result – that's what we'd like to know. What's the end result? What are you going to do to prove?" "It would be nice if they could say 'Yours (water) is just perfect, fine.' Instead they came and didn't say a word."

1.5.4.3 Summary of Water Treatment Plant Operator Interviews

WTPOs were interviewed at each of the communities while classroom demonstrations were being conducted. Table 1.4 provides quotations from interviews with WTPOs that illustrates general concerns with lack of funding to keep the plant operating effectively. Most water treatment plants have only one fully qualified operator, which makes it difficult for operators to take time off and to work regular hours. There is a lot of pressure put on the operators and they feel great stress and responsibility for providing safe drinking water for their communities. It is difficult to find operators who are willing to take on this role and further complicated by challenges getting funding for operator training and providing adequate salaries for certified WTPOs.

There is a trend toward combined biological filter reverse osmosis water treatment plants in many of Saskatchewan, and Canadian, First Nations. WTPOs see this plants as easier to operate and less likely to fail due to the success they have had on other communities. The operators and community members view them as more environmentally friendly because they do not use potassium permanganate and use less chlorine.

Table 1.4: Themes and Quotations from Water Treatment Plant Operators Interviews

Themes	**Quotes**
Trend Towards Biological and Membrane Filtration	"But by going to IBROM system, the biological system, I know that we will save approximately 90% of our chemical budget" "We could just look at the manganese greensand filters, clean them out, replace it with ceramic material used for attachment of bacteria… that has worked extremely well"
Distribution Systems	"The big thing, I think, with (our cisterns) is that when they installed them, they don't pay attention to the installation." "You're limited to 1000 gallons of water a week. I challenge any family in Canada to live on a 1000 gallons of water a week. As you heard me mention before, people have to make a decision: flush that toilet, do a load of laundry, wash dishes." "there were a lot more gastrointestinal problems (with cisterns), than there are (with centralized distribution)"

1.5.5 Conclusion

The RBC project with the COE, SPH and FHQTC focussed on understanding communities' value of water as a physical and spiritual resource. In exchange for the time and insight of community members, the research team gave science demonstrations for elementary and high school students. Lunch, prizes, and honorariums were provided along with the science demonstrations and interviews. The knowledge gained through these visits directed the focus of subsequent research and publications. The communities expressed frustration with not having any tangible outcomes with past research projects and not being included or consulted on past projects.

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Chapter 2: Co-design of water services and infrastructure for Indigenous Canada: A scoping review

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Abstract

There is movement in engineering fields and in Indigenous communities for enhancement of local participation in the design of community infrastructure. Inclusion of community priorities, and unique cultural, spiritual, and traditional values harmonizes the appearance, location, and functionality of developments with the social and cultural context in which they are built and contributes to holistic wellness. However, co-design processes that align community values and the technical needs of water facilities are difficult to find. A scoping review was conducted to explore the state of knowledge on co-design of water infrastructure in Indigenous Canada to build a knowledge base from which practices and processes could emerge. The scoping results revealed that articles and reports emerged only in recent years, contained case studies and meta-reviews with primary (qualitative) data; and involved community members in various capacities. Overall, thirteen articles were reviewed that contributed to understanding co-design for water infrastructure in Indigenous Canada. Barriers to co-design included funding models for Indigenous community infrastructure, difficulties in engineers and designers understanding Indigenous worldviews and paradigms, and a lack of cooperation among stakeholders which contribute to ongoing design failures. A working definition of *Co-design for Indigenous Water Infrastructure* is presented.

2.1 Background

Co-design and value sensitive design are established approaches to development and technology that include engagement with end-users, reflection by designers, and incorporation of human values throughout the design process (Friedman, 1996; Friedman et al., 2013). Originally introduced as a process for including human values in computer software and information systems, *co-design*'s principles have applicability across a range of contexts, for example, pharmacology (Timmermans et al., 2011), design of health care centers (Walton and DeRenzi, 2009), military applications, and as a pedagogical tool for university students for directing their learning (Cummings, 2006). A new context in which use of co-design is growing is in the design of water and wastewater infrastructure. In Canada, there is a trend toward increasing the inclusion of culturally unique values and local priorities in the design of community infrastructure and services (Nelson-Barber and Johnson, 2016). Researchers have noted that co-design processes benefit all through capacity building; increased motivation, confidence and trust; alignment of goals among community members and service providers, and enhanced holistic health (Donetto et al. 2015; Robert et al. 2015). Examples include the building of the Gordon Oaks Red Bear Student Center at the University of Saskatchewan, and the Justice Institute of British Columbia's Aboriginal Gathering Place (Charbonneau, 2016).

Projects that incorporated community values and input in the design process exist in several countries. Both the National Museum of the American Indian in Washington, D.C., and the First Peoples Hall in the Canadian Museum of History in Gatineau, Quebec, include style, aesthetics, character, and materials that reflect Indigenous values, and were designed by Indigenous architects (Phillips, 2006). Memorials built within the last three decades in Cambodia, Rwanda, and Germany worked to connect tourists and other visitors to the 'memory-scapes' of local people (Davis and Bowring, 2011). The Meulwater Water Treatment Works in South Africa is lauded as a water treatment plant with advanced design and technical efficiency. However, it is also recognized for enhancing heritage and cultural values of the Drakenstein Municipality through its alignment with, and sensitivity to, the local social, ecological, and cultural environments (Meulwater WTW, 2013).

Though these projects have shown success in the co-design process across tourism, recreation, housing, and community service projects, outside norms are not always validated in water and wastewater treatment design (Martin, 2014; Black and McBean, 2017). Infrastructure design textbooks and manuals, for example, sporadically contain reference to the inclusion of cultural values and rarely contain guidelines for engaging with Indigenous communities (Sandercock, 2003; Grant, 2010). It is recognized that stakeholder priorities should be integrated into the decision making process for community infrastructure to promote successful project outcomes, however, this inclusion has not been advanced in work with Canadian Indigenous communities (Richardson et al., 2012; Martin et al, 2007; Daley et al., 2015; Black and McBean, 2017).

As a part of Canada's commitment to reconciliation and within the calls to action of the Truth and Reconciliation Commission, resources for improvements to existing services and infrastructure, and the development of new infrastructure for health care, education, housing and other needs on Indigenous lands are being discussed (Anaya, 2015; Reading et al., 2016; Truth and Reconciliation Commission of Canada, 2015). One prominent need is access to safe drinking water across reserves in Canada. As a step in understanding the barriers to incorporating co-design and value sensitive principles into the design of water infrastructure for Indigenous communities in Canada, this scoping review sought to discover descriptions of these projects in the Canadian context. The goal of this paper is to describe the academic and grey literature on community co-design of water infrastructure on reserves in Canada.

2.2 Co-Design Defined

Definitions of co-design (and its related terms; value-sensitive design, co-creation, collective creativity; co-evolutionary design; empathetic design; user-centered design, participatory design) are bounded by disciplinary and contextual factors (Winschiers-Theophilus et al., 2010; David et al., 2013). Co-design can mean the development of ideas from the party being serviced; a collaborative process with knowledge sharing towards building a product; the move towards user-involvement as a means for ensuring higher product quality and consumer relevance; and, in global development, it is the evolution towards participatory methods framed by discourses on social embeddedness and the importance of local factors in technology appropriation (Sterling and Rangaswamy, 2010; Davidson-Hunt et al., 2012; Winschiers-Theophilus et al., 2012). Put simply, co-design means that local people are active in the creation of products ranging from coding for software to the design of large buildings and political or economic systems.

Co-design processes include common steps; stakeholder consultation, problem definition, idea generation, concept testing, prototype testing, product manufacturing, and evaluation (Sanders and Stappers, 2008; Staunstrup and Wolf, 2013; Frow et al., 2015; Deo et al., 2016). Different levels of participant involvement in co-design processes across various fields include being informed, consulted with, involved, actively collaborative, given empowerment opportunities, and also be central driving units and performers of co-design work (Nyerges et al., 2006; Bovaird and Downe, 2008; Pini, 2009; Sanders and Simmons, 2009).

Collaborative process in co-design projects have had positive effects on community health, economies, biodiversity, conservation and stewardship practices, and sustainability (Kambil et al., 1999; Botero and Hyysalo, 2013; Marin et al., 2016; Moser, 2016). In some co-design projects, stakeholders build capacity by performing tasks for themselves through coaching (Sampson et al., 2015; Galvin et al., 2016; Thorpe et al., 2016). While the benefits provide ample argument for using co-design processes, some constraints have been reported. First, the *ad hoc use of co-design processes* for products means that architectures for engagement are often missing or unequally balanced among the project teams. Secondly, the *tyranny of participant decision making* results in lengthy project timelines and project management challenges. Along with budgetary constraints of collaborative processes, these two are the most frequently cited constraints (Frow et al, 2015; Hickey and Mohan, 2004; Ramirez, 2009).

As a practice, co-design in the engineering and infrastructure design fields have progressed, however, the uptake is only now growing across Canadian and Indigenous contexts (Walsh et al., 2015; Schäfer and Scheele, 2017). With focus on developing sustainable water treatment systems resilient to impacts, and with a focus on reconciliation in Canada, incorporating the principles of co-design in Indigenous communities offers an opportunity for empowerment and capacity building vital to ensuring drinking water security.

2.3 The Research Gap and its Importance

Little has been published on processes of co-design specifically for water infrastructure. In design principles for the civil and environmental engineering fields, there is a heavy focus on treatment technologies and efficiencies, and reducing impacts in water treatment processes (Zhou and Smith 2002; Palit 2014). Emphasis is also given to measuring performance of water utilities, sustainability of infrastructure and customer satisfaction (Haider et al., 2015; Han et al., 2015). Calls for more holistic evaluation of water and wastewater infrastructure, processes, and performances for community wellbeing have been made (Haider et al., 2015; Ojuondo, 2015).

Case studies in Indigenous Canada describe little flexibility in the way infrastructure can be designed. For example, the guidelines from government agencies promote the replication of existing models of water treatment facilities at different sites (Mirosa and Harris, 2012). Water infrastructure is imposed on community members by engineers and contractors, and Chief and Council members are left to manage infrastructure based on priorities arising from federal programs (Murphy et al., 2015). Even in cases where research on novel systems is positive, the federal process limits a community's ability to adapt the design to one that meets their cultural needs (Walters et al., 2012).

The development of water infrastructure, regardless of the design process, is associated with improving the health and quality of life for communities; however, problems can arise with ongoing operation and maintenance (McCullough and Farahbakhsh, 2012; Basdeo & Bharadwaj, 2013; Black and McBean, 2017). Current policies on design and installation of water infrastructure reinforces ongoing colonization and strains communities financially and operationally (Black and McBean, 2017). For example, in Weagamow First Nation in Northern Ontario, the community water treatment plant was unable to operate for long periods at the capacity needed for the growing community. The heavy operation stressed the system causing malfunctions that the community did not have the capacity to address leaving them without water for weeks (Troian, 2016).

Looking forward, the goal of this research is to identify examples where co-design of community water infrastructure on reserves has occurred in Canada; key principles that guide the process of co-design in that context; and lessons learned. A scoping review was deemed most appropriate given the recent emergence of literature and the relatively new movement toward participatory infrastructure design in Canada.

Next, the paper continues with a description of the study context, the approach and methods, and the results. Discussion and conclusions are provided with a focus on identifying key gaps in the literature and research programs and recommendations on filling those gaps.

2.4 Study Context

In Canada, there are over 600 First Nation communities that were, in whole or in part, relocated from traditional territories to reserves set aside for their use (AANDC, 2014). Reserves are often in remote areas with low population densities which creates hurdles for access to reliable drinking water (AANDC, 2011). The climate, especially in northern reaches, provides challenges for the development of infrastructure; some communities experience short construction seasons with limited accessibility by road. Others have requirements for more expensive water systems to supply water through the cold winters without freezing and damaging infrastructure, or to improve very low quality source water (Smith et al., 2006; Maal-Bared et al., 2008; Grover, 2011). Most of the drinking water systems in these reserves are classified as small drinking water systems (serving fewer than 5000 people) (National Collaborating Centres for Public Health, 2009). These systems are plagued with technical and management problems: treatment plant age and suitability; inadequate training of operators and high turnover of staff due to poor working conditions; inadequate treatment of source water due to calculation difficulties, depletion of chemical stock and difficulty repairing and maintaining equipment; lack of emergency preparedness; limited technical support when needed; and spatial and seasonal factors exacerbate the problems (Edwards et al,. 2012).

Other human factors and historical inequities compound the problem. Each reserve community is unique with varied social, cultural, political and economic systems. Top-down and one-size-fits-all approaches to fixing water problems on reserve has left a legacy of mistrust and contributed to little measureable progress (Daley et al., 2015; Morrison et al., 2015; Black and McBean, 2017). Introducing new approaches including co-design and resulting trust and commitment to collaborations for enhancing water infrastructure on reserve are needed (Castleden et al., 2017).

2.5 Approach and Methodology

The Safe Water for Health Research Team (SWHRT) is a conglomerate of members from ten academic departments, four government agencies, three non-governmental agencies, the Federation of Sovereign Indigenous Nations, and eleven independent First Nation community representatives in Saskatchewan. The team has been collaborating since 2008 towards community-based participatory research projects around water issues. The need for the research discussed here arose from the team's desire to follow evidence-based approaches for co-design in communities on upcoming projects. Few articles, however, that directly encouraged or described co-design processes could be found by the network of researchers on the team. Hence, a *scoping review* was deemed appropriate given the need to discover and map the extent of research, and categorize findings but not extrapolate data across a variety of cases as in a systematic review (Arksey and O'Malley, 2005).

The procedure for this scoping review was informed by Arksey and O'Malley's (2005) framework with new developments (Joanne Briggs Institute, 2015). Eight steps were completed concurrently among two researchers: defining the question, creating a search protocol and criteria, identifying relevant articles, selecting the sample, tabulating data, engaging with other experts for consensus over themes, collating, summarising and reporting the results of this sample (Table 2.1):

Table 2.1: Keywords (with synonyms) and syntax used for literature search

#1	Water Drinking water OR water quality OR potable water OR healthy water OR drinkable water OR drink water OR drink OR safe water OR water OR suitable water OR palatable water OR edible water OR tap water OR fresh water OR water supply OR source water OR raw water OR wastewater OR waste water
#2	Indigenous communities Indigenous people OR Indigenous OR Aborigine OR Aboriginal OR Indigenous community OR Native(s) OR Indigen* OR Indigenous people OR First Nations OR Métis OR Inuit OR Inuk
#3	Co-design Co-design OR collective creativity OR co-creation OR empathetic design OR user-centered design OR participatory design OR Value sensitive design
#4	Infrastructure Infrastructure OR system OR building OR structure OR treatment plant OR plant OR piped distribution system OR water pipe(s) OR water system OR cistern OR tank
#5	Canada Canada OR North America
#6	#1 AND #2 AND #3 AND #5
#7	#6 AND #4

Next, article screening was completed and eligibility criteria applied to determine the in-scope articles. Screening meant the removal of duplicate articles and articles deemed irrelevant. There were three criteria used for eligibility. First, only peer-reviewed articles, reports or government documents were included. The next criterion was that the articles should be published no earlier than the year 2000. Lastly, only articles published in English or English/French were suitable for inclusion.

The two scope reviewers met with SWHRT members to come to consensus on the summarized results. Feedback from SWHRT also provided a framing for the recommendations arising from the work.

2.6 Results

Articles were retrieved and analyzed between June 2016 and March 2017, and are summarized by design, relevant findings, and limitations (Table 2.2).

Table 2.2: Summary of articles in scoping review

ID Authors (Year) Topic *Site (FN – First Nation)	Design: Method Data type, *N* Response Rate	Summary of relevant findings	Limitations
A Horning, Bauer & Cohen (2016) Social network analysis of watershed planning and water governance configurations in Canada *Similkameen Valley and Kettle River, British Columbia	Case study Primary data using semi-structured survey 2 networks explored (n=59 80% response rate n=54 69% response rate)	Both case networks demonstrated that collaboration is not supported. Centralized power brokers exist resulting in power asymmetry. In Similkameen, a small number of First Nations actors provide key bridging services. Missing links to industry and federal levels of government hinder policy progress.	Two case studies in one province, not longitudinal
B Halbe, Adamowski, & Pahl-Wostl (2015) Roles of paradigms in engineering practice with particular attention to 'community involvement'. *Flood case study: Hungary; Education case studies in McGill University Montreal, PQ, Canada and Uni of Osnabrueck, Germany.	Case Study Primary, qualitative data. Two cases: one on flood management, one on incorporating new paradigms into university-level engineering pedagogy	Application of solutions from one paradigm only is not enough to address the multiple aspects of sustainability problems. Both engineering and local community members have difficulty acknowledging the value of each other's paradigm. Teaching paradigms in engineering education could sensitize engineers to the value of diversity leading to "integrated management" paradigm.	Cases only in Westernized Nations (Hungary, Germany, Canada), small sample.

C McCullough & Farahbakhsh (2015) Refocusing the lens: Drinking water success in First Nations in Ontario. *FNs in Northern and Southern Ontario that were stratified across remote and accessible areas	Qualitative Interviewing: Grounded constructivist approach. Primary data 16 from snowball, stratified sample; recruited at a technical tradeshow in Toronto, Ontario.	Locally driven actions enhanced First Nations pride, capacity, and OCAP principles. Better infrastructure achieved through sidestepping Federal programs and processes to attain a desired goal. Satisfaction due to reduced bureaucracy.	No inclusion of negative findings Single province examined
D White & Leblanc (2015) Report on initial improvement to water and wastewater systems in 2013-2014 in Pikangikum First Nation, Northern Ontario *Pikangikum First Nation, Ontario	Case report Primary qualitative data: N = 10 family dwellings who had received piped water systems	Community members should be included in water infrastructure projects to build capacity, enhance health outcomes, and enhancement to water systems improve other issues in remote reserve communities through interconnectedness of water, health, energy, and social services.	Small sample, remote community, singular event
E McCullough, & Farahbakhsh (2012) First Nations drinking water infrastructure policy, and its translation, and action areas for reserves. * 16 FN reserves across Ontario	Case study Primary qualitative data (interviews) N = 13 interviews with 16 First Nations technical practitioners recruited voluntarily from trade-show	INAC accountability to external agents restricts its ability on technical challenges. INAC perceived as gatekeepers dominated by macro- and micro-control measures with no flexibility and too much frugality. Federal control interferes with accommodating diversity among First Nations. Northern FN's have limited capacity to execute a major capital works process, and retention of technical	Small sample size, one province, not representative. Lack of comparable research to draw from.

		stuff is poor. Northern communities have more challenging construction logistics. Engineers and workers not equipped to coordinate direct involvement of community leadership and navigate social structures of remote communities. INAC inflexible and incompatible with the diversity of FN communities – sharply contrasting INAC's mandate.	
F Simeone (2010) Reviews roles, responsibilities and progress of federal, provincial, territorial and First Nations governments for safe drinking water on reserve up to May 2010. *Federal, provincial, territorial, and local policy landscape	Content review and gap analysis. Secondary data. N/A	Water infrastructure on reserve is obsolete, absent, inadequate, or of low quality. Reserve communities have no mechanism to provide input on regulations. The focus of the federal government is on legislation, however, making legislation while infrastructure is inadequate to meet current requirements is questionable.	Data sparse. Poor consultation Failure to consider cultural dimensions of First Nations water use in legislation. Gap analysis found no pathways forward
G Smith, Guest, Svrcek, & Farahbakhsh (2006). Public health evaluation of drinking water systems in First Nation communities in Alberta, Canada *56 treatment plants in Alberta FNs	<u>Risk analysis site evaluation survey</u> conducted with environmental health officer and water treatment plant operator: Primary data; mixed quantitative and qualitative N = 56 systems	The process of design for small water treatment plants limited by funding. Systems are not user-funded and are constrained by the agencies who make decisions, reinforcing hierarchies. Needs to be locally determined and culturally relevant water sources, monitoring and treatment programs, and addressing of cultural,	Conservative approach to questionable situations in the study

		political, social, and economic environment	
H AANDC Water and Wastewater Infrastructural reports (2010, 2012, 2013) Investment reports on the federal government infrastructure development for First Nations water on reserves *FNs across Canada	<u>Government reporting</u>: includes background, enforceable standards, protocols, investments, and evaluations of systems across Canada N = 3	Annual report on water and wastewater infrastructure highlights success stories and lists spending on projects. The partnerships are defined as financial support from the government with First Nations planning submitted for approval	Does not provide a definition for design or descriptions for design process
I AANDC (2010) Design Guidelines for First Nations Water Works: policy statements and appendices	Content Analysis of Policy statements N/A	Plans for engineers to carry out successful design of water and wastewater infrastructure. It focuses on meeting technical standards for operation.	Lacks a component for community consultation
The following are included because of global relevance (not in Canada)			
J Ambole, Swilling and M'Rithaa (2016) Designing for Informal Contexts: A Case Study of Enkanini Sanitation Intervention *Western Cape, South Africa	<u>Case study</u>: participant observation and cross-case synthesis Primary data N = 3 cases (2 snap-shots, 1 longitudinal)	Inclusivity and human-centered design are concerns in design fields, especially for vulnerable populations. Capacity to participate and social pressures interfere with creativity and agency. Generative methods of co-design such as design ethnography allow for engaging transdisciplinary success. Socio-technological reciprocity approach allows reduction in power	Single case study, convenience sampling. No comparative research available.

		asymmetries. A co-design sanitation system was implemented, but social system to support the infrastructure failed due to poor communications, and reflection by team.	
K Tinoco, Cortobius, Grajales, & Kjellén, (2014). <u>Literature review, project reports, and field studies in Nicaragua</u> *Nicaragua and Caribbean coasts	Meta-review + Participatory action research in six communities N = 185 articles; 100 project reports; and stakeholder dialogue, transect walks, focus groups, interviews and mapping in six communities	Poor socio-cultural understanding of water and sanitation interventions abound. There is rejection of infrastructure and non-functioning solutions due to clashes with cultural preferences and local relevant knowledge. Results in inactive management organizations, and incomplete infrastructure installation. Lack of capacity to integrate Indigenous worldviews exists among designers. Wasted investments because facilities are not used/fall into disrepair	Field study limited to one country. Participatory, but no Indigenous methodology.
L Jiménez, Cortobius, & Kjellén (2014) Review of water and sanitation services across global Indigenous populations. *Global	Meta-review Secondary data 185 articles N/A	Analyses of power struggles and conflict appear often, while legislation and institutions, though increasing in their acknowledgment of the rights of Indigenous people, are failing at practice. Differences in values for water and health contribute to disparities. Indigenous participation in planning processes is increasing, however need more tools to facilitate. Awareness needs to increase. Researchers need to find processes that respect both the requirements of the	Sample over-represented by political ecology papers focusing on conflicts. Literature lacking in success stories. Omitted large selection of articles on TEK. Few papers from Africa because of Indigenous-Colonial reversal

		external agents, and local structures and workflows.	
M Murcott, S. (2007) Co-evolutionary design for development: influences on engineering design and implement *Nepal	<u>Case study</u> of household water filter co-development and experimental testing in Nepal to develop a 10-step framework for co-evolutionary development project	Co-development and experimental testing had four positive effects: increased public awareness of the problems, enhanced local entrepreneurship, innovation due to constraints of local material availability, and economic development. Other benefits included enhanced networking, empowerment of women, and better water.	Tech requires instruction or is dismissed thus experts need to be available. Small sample, unsustainable funding and no diversified funding sources, no long-term data.

2.7 Overview of Selected Studies

The total number of studies returned was 1551 (Figure 2.1). These articles were managed in a commercial database for easier processing. Most articles were removed as duplicates (n=966) before being screened for inclusion. After the removal of duplicates, screening for inclusion criteria, and exclusion of irrelevant articles there were 13 articles for this review. For the screening process, irrelevant articles were those that were included by the keywords but did not have a core topic that reflected the keywords. This included four articles that were relevant in regards to the element of co-design, but were not conducted in Canada.

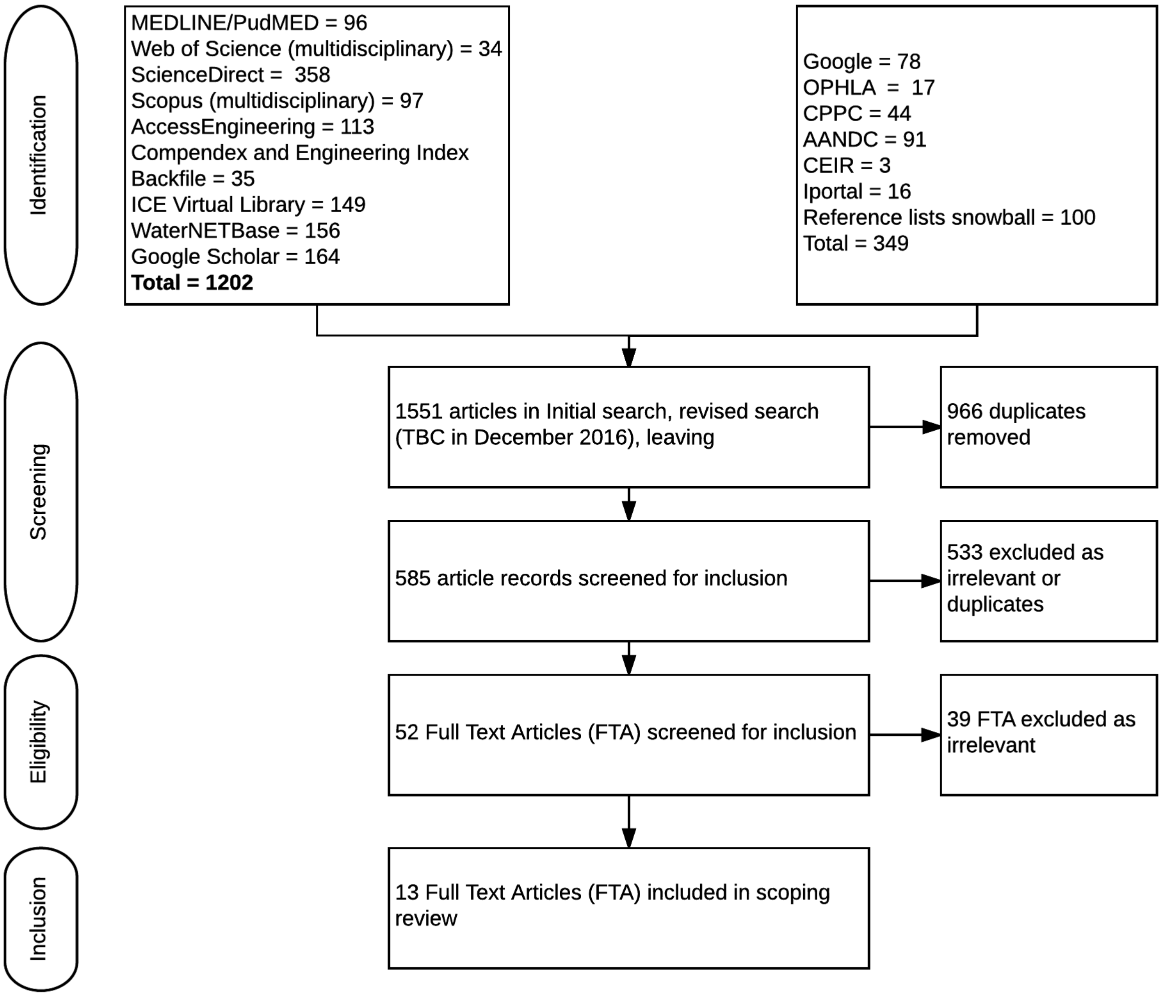

Figure 2.1: Scoping review process and step-by-step results

Table 2.3: General attributes of publications included in the scoping review (n=13)

Characteristic	Number (n=13)	Percentage (%)	Article ID numbers*
Publication year			
2006-2011	4	31%	(F, G, I, M)
2012- Feb. 2017	9	69%	(A-E, J-L)
Publication type			
Journal article	10	77%	(A-G, K-M)
Thesis or academic report	1	8%	(J)
Technical report	2	15%	(H, I)
Level of Participation			
Inform	2	15%	(B, G)
Consult	2	15%	(C, E)
Involve	2	15%	(A, K)
Collaborate	3	23%	(D, M, J)
Empower	0	0%	
None	4	31%	(F, H, I, L)
Indigenous Community			
First Nations	6	75%	(A, C, D, E, G, H)
Other	4	13%	(J, K, L, M)
None	3	13%	(B, F, I)
Definition			
Design	3	23%	(B, J, M)
Co-design	3	23%	(B, J, M)
Both	3	23%	(B, J, M)
None	10	77%	(A, C - G, H, I, K, L)

2.8 Study Characteristics

2.8.1 Descriptive summaries of study characteristics

General attributes of the articles resulting from the scoping review are summarized in Table 2.3. Many of the articles were published in the last five years (9/13) and in academic journals (10/13). The collection also included government guidelines and sets of annual reports. The studies involved First Nation communities and groups in Canada (6/13) and Indigenous groups outside of North America (4/13). Most of the sample did not have definitions for design or co-design. The ones that did (B, J, M) had a definition for both design and co-design (Table 2.3). The definitions for co-design were similar in the three articles, but were not as specific as academic definitions which focused on process steps (problem definition, idea generation, concept evaluation, lab research, experimentation & analysis, detail design, fabrication, testing, and evaluation in both lab and field). One article (B) defines the process of co-design as when stakeholders are consulted on problem definition and then are engaged to some degree throughout the project; and engineering design as, “the use of heuristics to cause the best change in a poorly understood situation within available resources” (p. 272), suggesting a common-sense approach to problem solving. Another article (M) described co-design as relational, knowledge-sharing learning process meant to enhance ‘design for the common good’ and involving foreign and local experts and an understanding of the environmental context in which design was sought. For comparison, the Canadian Engineering Accreditation Board uses the following definition of engineering design “Design integrates mathematics, basic sciences, engineering sciences and complementary studies in developing elements, systems and processes to meet specific needs” (Canadian Engineering Accreditation Board, 2016, p. 31). It is significant that Engineers Canada indicates that complementary studies are important for design, however, no official definition, policies or practices for co-design were found within Engineers Canada resources.

Table 2.4: Methodological characteristics of publications included in the scoping review (n=13)

Methodological characteristic	Number (n=13)	Percentage (%)	Article ID numbers*
Research design			
Participatory research	2	15%	(C, G)
Case study	6	46%	(A, B, D, E, J, M)
Meta-Review	3	23%	(F, K, L)
Report	2	15%	(H, I)
Research data			
Primary data	8	62%	(A-E, G, J, M)
Secondary data	3	23%	(F, K, L)
Not reported	2	15%	(H, I)
Study Type			
Quantitative	1	8%	(A)
Qualitative	7	54%	(B, C, D, E, J, K, M)
Mixed	2	15%	(G, L)
N/A	3	23%	(F, H, I)
Participatory Process			
Survey	1	8%	(A)
Education	1	8%	(B)
Interview	3	23%	(C, E, K)
Working Group	3	23%	(D, M, J)
None	5	38%	(F, G, L, H, I)

2.8.2 Reported methods

Articles in this sample used qualitative (7/13) and quantitative data (1/13), while two used mixed data (2/13) (Table 2.4). Other articles were theoretical or practical in nature and did not use data in the analyses. Articles were mostly case studies (A, B, D, E, J, M), but also included meta-reviews (F, K, L), participatory research (C, G), and government reports (H, I). One qualitative case study (J) focused on a project initiated by a community in which the co-design process was used to plan out the collaborative effort needed for the study. The parties involved worked together to produce the principle outcome of the study; prototypes for wastewater infrastructure. Another case study (B) used a literature analysis of paradigms in engineering practice and Integrated Water Resource Management (IWRM) examples to build content for educational tools to improve student's skills in engagement. The literature analysis uncovered six paradigms that students needed to be sensitized too prior to teaching practical approaches for community involvement.

A mixed data review (G) of water infrastructure on First Nations was included as the authors conducted the review to determine trends in the state of drinking water facilities. In the review, water treatment plants were examined with data inputs in the form of water quality testing, risk assessment survey results and qualitative assessments by environmental health officers of treatment plant operators in 56 systems. Overall concern with the condition of treatment plants was high and credited to an inhibitive funding framework and poor local consultation.

The variety of methodologies and data types in the sample give evidence of the potential data available for examination across complex systems, however, none of the studies in the scoping review used the same methodologies that would allow for cross-sectional evaluation of systems of water infrastructure. Only four studies in this review included arguments for their methodology (A, C, E, G) and none presented alternative methodologies.

2.8.3 Reported data collection approach

Primary data was gathered in eight studies (A-E, G, J, M), while three (F, K, L) used secondary data and two were unreported (H, I) (Table 2.4). The sample was categorized by level of participation as either *informed, consulted, involved, collaborated, empowered, or not reported/none* (based on the definitions from Nyerges et al, (2006); Bovaird and Downe, 2008;

Pini, 2009; Sanders and Simmons, 2009). The sample included two studies that described the informed level (B, G), two consulted (C, E), two involved (A, K), and three studies reported collaborating with communities (D, M, J). Four articles/guidelines did not report any community involvement (F, H, I, L).

Articles reporting participatory approaches used educational sessions (B), working groups (J, K, M); and used local people as community coordinators, data collectors, or other project personnel (J, K, M).

2.9 Methodological Limitations

Articles were examined for limitations or biases that would impact credibility. The most consistent limitation was the sample sizes and difficulty in generalizing results (A, D, E, J). Further, for the articles that focused on Canadian Indigenous populations, studies were limited to a single community. No treaty areas were identified as study sites giving further evidence to the lack of contextualized information among researchers and contractors serving Indigenous Canadian water infrastructure needs.

Two inclusions that described infrastructure and policy (F, G) failed to execute any consultation or explain the rationale for not consulting with Indigenous groups on Indigenous policies as a part of building the guidelines or implementing them. In the qualitative perceptions of-, and mixed data reviews of infrastructure and operators (C, E, G), the researchers involved water treatment operators in the examination process but did not involve them in analyses or formation of conclusions. A lack of review of cultural dimensions of Indigenous water use was found among most studies included in the review (except J and K). Consistent throughout the sample was a lack of reporting on procedures that employed cultural methods or tools for gathering or analyzing information. In summary, only one study (K) examined the relationships between Indigenous culture and water infrastructure.

Results of the government guidelines and documents (H, I) and a perception study (C) focused on the success stories of water projects in Indigenous Canada, however, lessons learned were underreported except in the case of the South African wastewater sanitation project (J) whose failure led to community and research team reflection.

2.10 Thematic Analysis and Study Findings

Themes arising from the scoping review included the poor state of the water infrastructure on Indigenous reserves in Canada; the co-design processes themselves; difficulties in the process which interfered with implementing co-design; and a belief that a major challenge to success of these projects is the lack of cooperation and willingness to understand other paradigms when it comes to engineering and design.

2.10.1 State of water infrastructure and design on First Nations

The condition of existing water infrastructure was discussed in some of the articles along with challenges involved in the process. Some studies (C, E, F, G) reviewed the infrastructure and stated that it is often obsolete or inadequate and leads to a loss of access to clean drinking water. The difficulty in resolving the state of repair was suggested to be a product of risk- and engineering-centered guidelines, and a funding structure that is difficult to navigate (C-G). Authors described the current systems as not value sensitive and therefore missing the element of ownership required for successful upkeep (C, E, M). Authors also perceived that as a result of government funding formulas, projects lack the uniqueness necessary to address social, technical, cultural, and political factors that are specific to the target community (B-G). When a system fails to meet these needs, its success is limited (C, E, J-L). Among the guiding documentation for the design and implementation of water infrastructure on reserves (H, I), there were no policy statements or standards on respecting cultural values, or protocols for collaboration. There are, however, policy statements on ensuring the security of infrastructure to threats in addition to technical specifications for each type of water treatment system suggesting a risk-based and engineering-centered approach.

2.10.2 Co-Design Processes Presented

Four processes were presented in the included articles as methods of co-design. First, six articles look specifically at the challenges of *federal (central government) control of design*, where funding agencies specifically mandated Indigenous consultation and local implementation of water infrastructure for Indigenous people (C-I in Canada, K in Nicaragua). The process includes Indigenous communities submitting applications to federal agents, often through consultants. Federal agency power over the design process has been critiqued as lacking in financial accountability, and being too frugal and controlling on both micro and macro scales (C-E, G). In addition, the process has been minimally effective for only the most vulnerable communities (D, E). Poor dialogue between central government agencies and local Indigenous people also results in unsuitable institutionalization and poor maintenance and operational functioning of water systems (K). Although the requirements of the federal application system include physical aspects such as expansion potential, plant and building layouts, location, power source, controls among others (H, I) guidelines for community engagement and involvement on the design, and inclusion of social and cultural considerations are lacking.

Secondly, the *watershed planning process* was evaluated in two British Columbia First Nations communities for its ability to create a collaborative environment (A). Through B.C.'s new Water Sustainability Act, watersheds are encouraged to seek out meaningful involvement of all water actors including water purveyors, (e.g. irrigation districts), First Nations, industry, government institutions, and nongovernment organizations to develop sustainable watershed plans. The process of creating a watershed plan was evaluated through social network mapping. The authors concluded that the planning networks "evolved a distinct core-periphery structure, which has a tendency to reinforce the dominance of centralized power brokers in framing the dialogue, controlling information flow, and privileging certain outcomes over alternatives" (A, p. 9). Further, they describe that bridging actors are not sufficient to overcome the problems of disconnection between diverse stakeholders, and at minimum, more funding is required to include First Nations in the planning process.

Third, the *co-evolutionary design for development process* was examined in the context of the design and implementation of an innovative arsenic and microbial remediation filter for households in Nepal (M). The process includes ten steps; problem awareness through partnership, problem co-definition, idea co-generation, concept co-evaluation, experiment/analysis in cultural context, prototyping from local materials, design refinement, piloting, implementation and scale-up, reiteration and reinvention (M). While the approach was deemed successful through the implementation in this case study, the authors caution that more time is needed to evaluate the long-term uptake of the technology they co-created, as well as more global awareness of the time their processes take to implement and follow-through (M).

Fourth, the methodological approach of *infrastructuring, design ethnography, and core design competencies* as a unit was explored over the course of a 2 year case study in South Africa (J). Within the frame of ‘infrastructuring’, where collaborative design exercises can be sustained to achieve long-term social change, the change agent (designer who works from both professional design and anthropological/ethnographical lenses) facilitates the emergence of ideas from the collective imagination. The agent also provides expert design advice and, thereby supports the creation of contextualized solutions (J). The specific social, cultural, ecological, communication and economic needs become part of the core design competencies that are sought from the ultimate solution. The case study authors caution that while ‘infrastructuring’, design ethnography and competency development can serve to enhance transdisciplinary problem solving, effort needs to be made to ensure participants from vulnerable communities have clear exit strategies, the pace of research is fluid and is guided by community participants, and the design ethnographer is accepting of poor participation, conflict, and design failure.

2.10.3 Challenges to Evolving the Design Process/Merging Paradigms

A common theme of discussion is the potential for successes that accompanies co-design processes, but also the difficulties adjusting paradigms among partners (A-E, J-L). It is suggested (B) that it is not enough for only one paradigm to be used when addressing community-based problems. The involvement of co-design processes is becoming more prevalent (A, C, D, J-L, M), however, networks of partners involved in the co-design process are hierarchical in nature, and not equal in membership among local, government, and industry partners (A). There is recognition among study authors and their participants that active collaboration is critical to creating human-centered infrastructure (J-M), but there is difficulty addressing the gap between those who subscribe to a conventional understanding of the design process. Differences in expectations for involvement among actors is cited as an obstacle for consulting engineers, designers and government agencies (A, B, J). The normal measure of success was defined by articles in the sample as meeting technical standards (C, D, E, H, I). Some allude to the need to include social, cultural, ecological and economic standards (D, E, J, K, M). The paradigms where communities are involved at meaningful levels and traditional knowledge is recognized equally go deeper to address the broader needs of communities (E, J-M).

2.11 Discussion

A pool of 1551 articles was narrowed to 13 relevant articles. Many of the articles made reference to the numerous challenges faced when designing and implementing water projects on Indigenous reserves. Challenges included the funding framework; the debate for whether to employ a design process that addresses the unique situation of a community's needs, or a conventional approach to meet the funding requirements; difficulties bridging paradigms of conventional design processes with community social, cultural, and political values through co-design processes; and unequal hegemony and networks of partners involved in water infrastructure design. Although there was the impression within the sample and in the literature that a collaborative process was in the best interest for a successful outcome (i.e., Marin et al., 2016; Moser, 2016), few articles in this sample defined what that process would be, and no actual examples of non-hierarchical approaches were found from within Canada. Further, most of the articles did not describe the need for, or actually involve, the community in a way of increased participation beyond the informed level. Only three of the studies involved stakeholders in an engaged or collaborative effort to find a community-based solution to address a water problem as defined by the community, and these studies were not completed in Canada.

No evidence of whether the *tyranny of participant decision making* affected outcomes of projects in Canada due to a lack of examinable cases; however, it is evident that globally, the *ad hoc use of co-design processes* is occurring and may be contributing to the impromptu uptake of co-design for water infrastructure. A lack of guiding documents, critical mass of work for review and lessons learned for practitioners from academics means little progress has been made on reconciling definitions, processes, and worldviews related to water infrastructure co-design. Contrary to this, however, a grassroots movement among Indigenous water experts and some academic partners has developed a three stage conceptualization of how community co-design for water could work (Aboriginal Water and Wastewater Association of Ontario, 2014). The stages include knowledge sharing, grounded guidance, and solution formation, and community values act as the standards by which proposals are evaluated against.

At present, the co-design processes for water infrastructure occurring in Canada have yet to move beyond perfunctory stakeholder consultation, with little contextualized problem definition, and co-creation of solutions grounded in community values (Frow et al., 2015; Deo et al., 2016).

Without flexibility in government guidelines or funding, there is little incentive for co-design by local people, civil engineers and architects. The INAC website promotes safe water by indicating that the Federal Budget earmarked $1.8 billion over five years for on-reserve water and wastewater infrastructure, “to address health and safety needs, ensure proper facility operation and maintenance, and end long-term drinking water advisories on INAC-funded systems on reserve” (INAC, 2016), however, individual reserves are dependent on the use of external consulting engineers to design infrastructure in accordance with established INAC standards. The hierarchical nature of the overseeing agency means that the level of engagement, capacity building, and opportunities for empowerment among reserve communities is controlled by consultants and federal agencies, and is limiting collaboration at the decision making level. This control also limits ethnographic research opportunities that may advance the field. No opportunities for local empowerment on co-design processes as the reconciliatory ideal, have been reported.

While there has been attention on the need to reduce risks from drinking water in Indigenous communities in Canada, solutions have been focused on improving operator training programs, providing more funding for federal government agencies to distribute, and improving the technology for small water treatment systems (Simeone, 2010; Kayser et al. 2014). Recurrent calls from researchers that these foci have been identified through misinterpreted evidence have not yielded changes in approaches (McCullough and Farahbakhsh, 2012; Cave and Plummer, 2013; Castleden et al. 2017). This scoping review points to the need for solutions driven by mindset changes among professional engineers, scientists, architects, and others involved in the design of water infrastructure as well as providing a pathway for Indigenous voices to be heard. The human dimensions of drinking water systems need consideration to reduce not only technical risks, but cultural risks (Kot et al., 2014). To this end, we suggest the prioritization of research towards understanding how Indigenous Canadians want to proceed for the provision of drinking and wastewater services on reserves.

The gap between trust in conventional versus co-design is wide in this study context as is in other contexts (Forlano and Mathew, 2014; Nelson-Barber and Johnson, 2016; Khovanskaya, 2017). Evidence also supports the idea that communities do not believe that infrastructure controlled by outside sources and not informed by the community can succeed (Boyd, 2011;

Martin, 2014; Dyck, Plummer and Armitage, 2015; Black and McBean, 2017). Similarly, there seems to be a reluctance by industry to adapt their procedures to include listening to the voice of the community at all stages in the design process, let alone supporting community members to drive the co-design process in a decolonized way (Bhat, 2015; Black and McBean, 2017; Joyce, 2017). The evidence of successes and lessons learned from water infrastructure implementation in Indigenous communities that we came across were researcher-driven and used novel co-design processes (Ambole et al. 2016; Wang et al,, 2016). In this sample, case studies provided advice for Canadian co-design sites to avoid rejection of water infrastructure. By focusing on relationships building, open and reflexive communications with local people with a dedicated social scientist/ethnographer, and encouraging flexibility and humility in co-design through using intercultural approaches, co-design of water infrastructure has the potential for success. Given the need for new water infrastructure on reserves in Canada, researchers, engineers, industry and government networks could make progress in developing co-design processes with the advantage of learning from other contexts (J-L).

A first step towards this would be calling for more pilot projects and examples of infrastructure co-design in Canada to be shared among mobilization pathways such as in journals, other online publications, and at conferences. Specific topics could include progress in integrating cultural values in design processes for all sorts of community infrastructure on reserve, problems with current designs of Canada water and wastewater infrastructure on reserves from the perspective of those living and working with these systems, and methods for engineers and designers to reflect on their practices and encourage co-design among their peers. Other recommendations include:

1. Creating an infrastructure co-design working group involving government, industry, Indigenous, and academic partners to examine potential processes
2. Working towards the inclusion of co-design principles and processes into textbooks, training, degree programs and other pedagogical material to encourage the next generation of civil and environmental engineers,
3. Increasing the flexibility in the federal guidelines and policies so that co-design processes for water infrastructure on Indigenous lands are supported

2.12 Conclusion

This scoping review revealed possible obstacles to current water infrastructure co-design paradigms. As in education provision, health services, and social services, a reliance on hierarchical decision making and patronizing approaches from the federal government continue to create barriers for Indigenous people to gain services equal to non-Indigenous people in Canada, and build capacity and sovereignty. Practitioners require more training to overcome discomfort with accepting local perspectives and knowledge relevant to water infrastructure design, and accepting that processes to co-create infrastructure solutions can be inclusive.

Water infrastructure in Canada has proved unreliable in delivering safe water to Indigenous communities. International examples of co-design processes that supported the emergence of innovations provide some lessons for Canadian researchers and practitioners. The issues with the Canadian system begin with the funding, guidelines and design processes, but also includes overcoming the challenge of co-designing from different worldviews. Although the scoped articles showed reflexive initiatives internationally, the Canadian sample is limited. There is a need for more reporting on, and evaluation of Canadian projects in Indigenous communities to be able to build on results. Future research should include studies from multiple regions in Canada for comparison.

A generally accepted definition of co-design for Indigenous communities in Canada would serve the engineering community well, and examples of protocols beyond hierarchical, watershed planning, co-evolutionary design, and 'infrastructuring' are needed. This would help industry practitioners understand co-design. To this end we put forward the following definition for Indigenous co-design for water services: *Indigenous co-design for water services is a process where local Indigenous people, their social, cultural, spiritual, and other values associated with water, and engineers and their values associated with water come together in respectful, reflexive, and equally represented ways to co-create and implement a shared process to design, test, and build infrastructure that sustains local environments, holistic health, communities, and cosmologies.* Further debate and research is required to inform a collaborative design process for water infrastructure projects on reserves in Canada.

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Chapter 3: Assessment of Costs of Centralized and Decentralized Water Systems on First Nation Communities

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Abstract:

Water systems on First Nations fail to provide safe drinking water throughout Canada. Many of these communities have individual, household cisterns as part of a decentralized water system that are prone to contamination causing health issues. It has been suggested that there is insufficient funding provided by Indigenous and Northern Affairs Canada (INAC) for water infrastructure projects on First Nations which is preventing communities from addressing these issues that can be mitigated by moving to a safer, centralized distribution water system. Currently, the funding formula used by INAC focusses too simply on the construction costs of water infrastructure projects without providing any consideration for human health related costs. This research presents a proposed expansion to the funding formula to include the potential costs associated with health and social impacts that a decentralized distribution system has on a community. After creating an updated formula, a comparison study was performed on an example Saskatchewan First Nation where the capital cost of a centralized and decentralized system was compared using INAC's funding formula. Additional annual costs were added to an updated funding formula showing a 'true' cost of decentralized systems based on human health related costs. Taking these added costs into consideration, it was found that the less safe decentralized system actual cost was higher than the safer centralized system for this example community. Overall, the methods of funding allocations for communities in need of upgraded water systems must be expanded to reflect long term impacts as justification for greater capital investment.

3.1 Background and Introduction

3.1.1 Drinking Water in Indigenous Canada

Human health in First Nations communities has historically been negatively impacted by poor access to clean drinking water (Waldner et al., 2017). Although the issue has been recognized, communities still struggle for solutions to drinking water challenges that must address technical, social, and political aspects specific to each community. The responsibility for providing water infrastructure on First Nations is shared by Indigenous and Northern Affairs Canada (INAC), Health Canada (HC), and Environment Canada (EC) (Bradford et al., 2016). This structure of multiple overlapping Federal departments has historically complicated the implementation of water, and other infrastructure, projects on First Nations. In addition, these departments generally only provide 80% of water infrastructure costs with the nation's Chief and Council being responsible for covering the remaining 20% of the infrastructure costs (typically collected via user fees in non-First Nations communities) (Bradford et al., 2016). This lack of full funding is an ongoing issue since First Nations distribute water without charge to their communities given water is considered a human right and has a spiritual resource beyond its utility as a physical necessity.

Funding issues directly impact the quality of water treatment and distribution to the community leading to the creation of health challenges in First Nations that have existed for decades. In Canada, it is more likely for a First Nations community to experience waterborne illnesses and to have at risk water infrastructure as compared to the national average (Boyd, 2006). Overall, there are 70 First Nations in Saskatchewan and 617 in Canada (Statistics Canada, 2011). Saskatchewan is home to 11.7% of Canada's First Nations population making up 10.7% of the total provincial population (Statistics Canada, 2011). Of these, 30% of water systems on First Nation communities are described as high risk (Black and McBean, 2017) which is defined by Burnside (2011) as a water distribution system that has major deficiencies that could impact the health of a community. In Saskatchewan, 26% of First Nations have high risk water systems (Burnside, 2011). There are a wide range of health issues that are prevalent on First Nations as a result of high risk water systems including gastrointestinal illnesses, skin disease, and kidney disease. Additionally, limited or restricted access to safe drinking water can also have an impact on mental health by causing anxiety and stress (Bradford et al., 2016). These health and social costs are not currently considered in the funding formula used to determine water infrastructure costs including the choice to install either centralized (piped-to-homes) versus decentralized (truck-to-cistern) systems. Generally, centralized water systems delivering water directly to household taps are less prone to producing human health issues versus decentralized systems that produce numerous potential contamination sources discussed in detail below.

3.1.2 Water Systems and Health

Despite technological advances that have led to improved drinking water treatment systems, there are still cases of failing Canadian water systems negatively impacting human health. Possibly the most prominent case in Canada's recent history was in 2000 with an *E. coli* outbreak in Walkerton, Ontario, where over 2,000 people were impacted by tainted water including 7 known fatalities (Lebel and Reed, 2010). In Saskatchewan, the 2001 outbreak of gastroenteritis in North Battleford affected approximately 6000 people (Hrudey and Hrudey, 2004). Given their populations, it is easy to track these large outbreaks in municipal supplies of larger communities. In contrast, health issues arising from small community and private water supply systems such as individual households' cisterns or wells are harder to assess and, in general, regulatory frameworks focus less on their protection (Kreutzwiser et al., 2011). This is a major issue given that Statistics Canada (2007) estimated that 5 million Canadians receive drinking water from small, decentralized systems each serving less than 300 people. Additionally, the Burnside report (2011) estimated that 26% of homes on First Nations in Saskatchewan are on a decentralized system. This value agrees with Duncan and Bowden (2009) that estimated 25% of prairie reserve lands are dependent on hauling water, which they call the "prairie problem".

There are several components of a community's water distribution system that can lead to the creation of high risk to human health due to poor water quality. For example, even if a community has an effective water treatment plant that produces safe drinking water, the lack of a centralized distribution via high-pressure piping leads to individual homes lacking safe water. Overall, the majority of First Nations in Saskatchewan have homes on a decentralized water distribution system (Burnside, 2011) that has various stages involved in transporting treated water from the water treatment plant to household taps that can result in contamination. Firstly, water is collected in a truck from the plant and then delivered to holding tanks (cisterns) to individual homes. Contamination of the clean water can occur during the filling of the truck or the filling of the households' holding tanks. Secondly, if the cistern is not properly maintained or replaced at the end of its lifecycle, it can fail in keeping out contamination such as pathogens, fecal matter, and chemicals. Additionally, when water delivery trucks are down for maintenance the community has to ration their water. Further, low-pressure centralized distribution overcomes the truck-related issues but still has the cistern issues given the water is distributed to the homes at low-pressure and generally stored in cisterns prior to use.

3.1.3 Economic Burden of Illness/Cost of Intervention

A lack of access to safe drinking water has the potential for creating negative health effects that have intrinsic economic consequences. The most common illnesses associated with waterborne pathogens are gastrointestinal issues with associated direct or indirect costs that have been determined previously. Direct costs may include: prescription medication, over the counter treatments, and provision of alternative water (usually bottled water). Indirect costs can include: lost time from work for the sick and their caregivers, lost business, and travel costs to healthcare providers (WHO, 2012). A 2006 study of these costs estimated the economic burden to be $1,089 per case (all dollar values in CDN unless otherwise stated) with an annual cost per capita of $115 (Majowicz, 2006). Comparatively, a 2008 study of a British Columbia town found similar results for cost per case and annual cost per capita as $1,342 and $130, respectively (Henson et al. 2008). These costs are typical for a household, but the economic burden is greater when an outbreak occurs impacting an entire water system. For example, a Cryptosporidium outbreak in Ireland was reported to have a cost of USD$142,000/day during a 158-day boil water advisory (Chyzheuskaya et al., 2017). During a 1993 outbreak in Milwaukee, WI, data from 11 hospitals showed that mild, moderate, and severe illnesses had total costs of USD$116, USD$475, and USD$7,808, respectively (Corso, 2003). The impacts of these types of outbreaks have been used to exhibit that the costs associated with reactive treatment of illnesses are often higher than costs associated with proactive infrastructure upgrades that would help to eliminate illnesses before they occur.

Intervention with water infrastructure can reduce the economic burden associated with illness. The World Health Organization estimates that with USD$11.3 billion of infrastructure upgrades that the worldwide annual savings would be USD$84 billion for elimination and/or reduction of costs for health-related treatments. However, the savings are region-specific making direct comparisons to Canadian infrastructure potentially incorrect. A more realistic comparison would be with the United States where the projected annual cost to get the entire population onto a piped network of water and sewer is USD$2.32 billion with a benefit of USD$9.01 billion (WHO, 2012). Failing and/or inadequate water systems on Canadian First Nations have gained notice by all levels of government with intervention efforts in the form of regulations and budget allocations. For example, the Canadian Federal government allocated $600 million over five years to support the 2003 First Nations Water Management Strategy (SDWF, 2008). However, these efforts have arguably fallen short of expectations across Canada. For example, by 2011 25% of water systems in Saskatchewan were still in a state likely to cause health concerns and drinking water advisories (INAC, 2011).

3.1.4 Current Funding Framework

First Nations Infrastructure projects are currently primarily funded by INAC's Capital Facilities Management Plan. The Cost Reference Manual (CRM) (2005) is an updated tool created by INAC in 1978 for the use for/by communities to estimate facility costs and to aid in planning for capital projects. This manual applies costs to components of a project (see Table 3.1) based on values typical for construction in Toronto, Ontario. Multipliers to these values are applied based on the 'remoteness' of a community that is determined by the distance of the community from the nearest 'city centre'. For communities in Saskatchewan these city centres include Regina, Prince Albert, Saskatoon, and The Pas (located in Manitoba). This remoteness index (RI) allows for a percentage of the cost of up to twice the amount of the Toronto model. Additionally, other site-specific indices are applied based on the nature of the site; required transport methods; and construction schedule, personnel, and administration. An example of this application is shown in Table 3.1.

The value for each criteria is multiplied by the other criteria to determine the site-specific indices for a project as follows:

[1] $$\text{Site Specific Index (SSI)} = \sum(a) * \sum(b) * \sum(c) * \sum(d) * \sum(e) * \sum(f)$$

For example, a Saskatchewan community 50km-350km from nearest city (remoteness zone 2) and with SSI shown in Table 3.1, would have its calculated project cost multiplied by a factor of 1.21. This is shown in Figure 3.1:

Site Characteristics:

- Lumber and building supplies not locally available
- Restricted lead time
- Level and treed project site
- Only semi-skilled and unskilled labour force
- One days travel for accommodation

Remoteness (Zone 2):

- 50 – 350km from nearest city centre

Remoteness Index (RI) = 1.10

Site Specific Index (SSI) = 1.03 * 1.01 * 1.01 * 1.01 * 1.00 * 1.04 = 1.10

(RI) x **(SSI)** = 1.10 x 1.10 = $\boxed{1.21}$

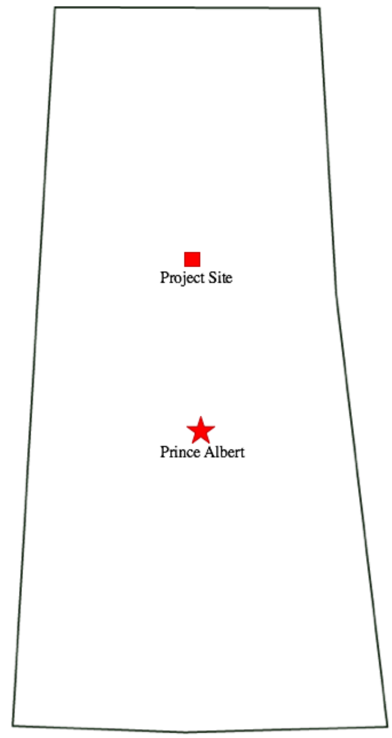


Figure 3.1: Determination of Cost Multipliers

Funds for water infrastructure projects are allocated by this method up to a maximum of $10,000 dollars per home plus 50% of the housing connection price. To qualify for centralized, high pressure piped water, the density of homes must average 3 units per acre and lot frontage cannot be more than 30 m (INAC, 2011) with alternative systems considered when density decreases past this point. These alternatives include decentralized systems (trucked water) and more limited centralized low diameter piped and low pressure piped water systems requiring cisterns. Based on INAC's Level of Service Standards, funding decisions are based on the lowest life cycle costing of these alternatives for a 20-year term.

Table 3.1: Example of the Calculation and Application of Site Specific Multipliers

Criteria		Multiplier %	∑ (Criteria)
(a) Materials	Lumber Not Locally Available	2	1.03
	Locally Available Aggregates	0	
	Building Supplies Not Locally Available	1	
(b) Administration	Restricted Lead Time	1	1.01
(c) Nature of Site	Normal Soil	0	1.01
	Level and Treed	1	
(d) Transportation	Road	0	1.00
(e) Personnel	Semi-skilled and Unskilled Labour	1	1.01
(f) Accommodation	Within Daily Travel	4	1.04
Value for SSI from Equation [1]		**1.10**	

3.2 Methodology

The overall goal of this research was to compare the funding formula used by INAC to fund water infrastructure to an updated formula meant to reflect the true cost of this infrastructure for a community. The INAC funding formula was taken from the 2005 CRM that provides Class C and Class D cost estimates for indicated infrastructure maintenance and/or upgrades. The item costs used were taken from the 'Water Supply, Treatment, and Distribution' section of the Facility Unit Costs in the Capital Cost Manual. The item costs from the CRM were compared to item costs from other industry sources to determine if there was any association between sources and/or justification of the values given in the CRM given the lack of referencing to real-world costs in this manual. The values from the CRM (2005) were compared to a recently completed water distribution project on a First Nation in Saskatchewan (2012), an analysis of three contractor bids for water service to a subdivision and low-density layout on a First Nation in Saskatchewan (2011) and a feasibility study of a low-pressure distribution system for a Saskatchewan First Nation (2017).

Only values from the CRM were used to calculate the capital cost of distribution systems to help maintain consistency. The total construction cost was then multiplied by the remoteness index and site-specific indices dependent on the project location. The following equation shows how the total cost was derived using the current funding formula:

[2] CRM Cost = (Construction Cost)*(Remoteness Index)*(Site Specific Indices)

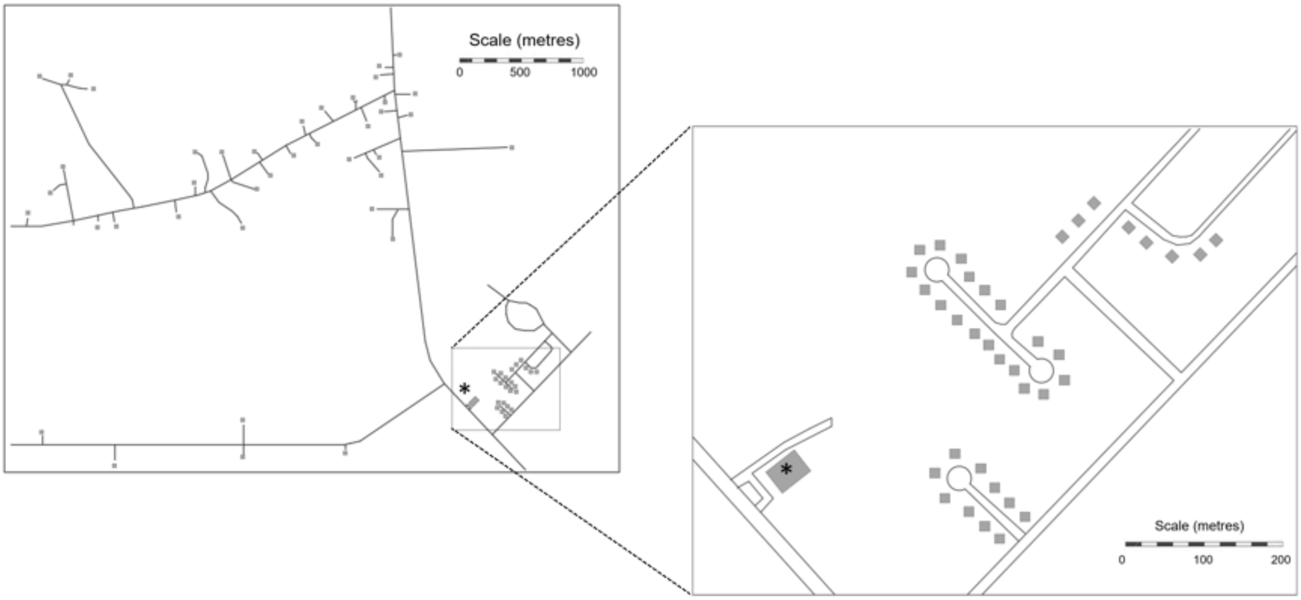
The values derived in comparison to this manual are also Class C and Class D cost estimates. The updated funding formula includes values beyond construction by including economic burden of disease, operation and maintenance of water delivery trucks, and impact on road infrastructure. These added costs are not meant to be exhaustive, they only serve as a first step to full cost accounting that currently excludes a number of relevant costs.

[3] Modified CRM Cost = Construction Cost + **Cost of Illness**

+ Water Truck Maintenance + Increased Road Maintenance

These formulas were applied to an example community of 100 homes (Figure 3.2) and using an average of 5 people/household as indicated by Statistics Canada (2011). The density of these homes is typical for rural households and piping lengths are based on similarly sized projects. The values for construction were taken from the CRM and were applied to compare the capital cost of centralized and decentralized systems.

Figure 3.2 shows what a typical community would look like with homes marked as grey boxes. Typically, the homes in higher density subdivision style layouts near the water treatment plant would receive piped, high pressure water (based on their higher density) and homes in a more rural (i.e., less dense) layout have cisterns. The centralized system calculation determines the cost to pipe water to all homes including the low-density rural layouts. This schematic is based on a community similar in layout and density to allow for comparison of the capital cost for centralized and decentralized systems.



(* Indicates the water treatment plant)

Figure 3.2: Schematic of Sample Community for Example Density and Layouts

It should be noted that Figure 3.2, although representative of an actual community, shows a distinct difference between the preferred living/household arrangements (anecdotally, subdivisions are not preferred) and the water distribution systems' usage. The homes near the water treatment plant, typically the only ones on centralized system, are shown in the inset figure. This shows how a community's living arrangements are dictated by water service rather than suiting water service to a more preferred, rural housing layout. The 'subdivision style' layout is used to meet the requirements for funding of a centralized system based on the lowest schedule of services from INAC. However, traditionally people on First Nations choose to live spread out in family units (McLoud, 2005).

The updated formula was applied in addition to the capital cost for the decentralized system as shown in eq. 3. The value for the cost of illness ($130) was taken from a study of economic impact of gastrointestinal illness on a Canadian community (Henson, 2008). This value was then adjusted to account for increased occurrence, greater travel costs and psychological impacts that translate to a Saskatchewan First Nation community (Patrick, 2010; Plummer et al., 2011; Reynolds et al., 2008). The operation and maintenance costs for water delivery trucks are allocated to communities based on the Capital Asset Inventory System. A sample agreement of what a typical heavy hauler truck would pay a municipality for its impact on rural roads was used to estimate the cost of extra maintenance and loss of road life from daily hauling of water in the First Nation community (Ministry of Highways, 2013). The updated formula is applied over a proposed lifetime of 20 years (based on INAC's Lifecycle Cost) to show the ongoing impact and justify greater capital.

Please note that the sources of the monetary values being compared are from different years and have therefore been adjusted for inflation using the consumer price index from the Department of Finance's Private Sector Survey (Department of Finance, 2017).

3.3 Results

Values and formulas presented above were examined to help better understand the overall funding process and to assess its validity. Cost of materials and methodology common to water infrastructure projects were compared to determine the basis of the CRM values and see if they were similar to other sources. The results are divided into three sections: updating of the funding formula; application to an example community; and comparison of common values. The first section shows how the funding of water infrastructure projects can be expanded to reflect a truer actual cost of the infrastructure's lifetime. The second section applies this updated funding formula to an example community to compare cost over a lifecycle of 20 years. The last section provides an overview of the values used in the funding formula from the CRM that were compared to costs of methods and materials from other industry sources on water infrastructure projects to see how accurate the CRM is in estimating projects in Saskatchewan.

3.3.1 Updated CRM Funding Formula

The CRM funding formula was updated to include indices other than construction costs taken from relevant studies (Henson, 2008; Ministry of Highways, 2013; INAC, 2011) for potential health impacts of contaminated water including the cost of gastrointestinal disease treatment, the operation and maintenance of water delivery trucks, and the increased road maintenance costs related to heavy water truck delivery impacts on community roads. These indices are not meant to be exhaustive in their extent of other issues but serve as a first step towards updating the CRM formula to more realistically portray the true costs. Additionally, despite the inadequacies of the

CRM indicated previously, its use for comparisons between centralized and decentralized systems was acceptable given it allows for standardization of the various unit costs.

Clean drinking water can be contaminated in various stages of a decentralized water system including during the filling of the water delivery truck, during the filling of cisterns, and within the cisterns. The contamination during the delivery process can be remedied via proper connections between the various water containers and having properly trained operators making the transfer. Unfortunately, cisterns at the home are prone to contamination (e.g., animals entering the cisterns) as the collars get damaged or the access is not securely restricted. It has been shown that some communities using cisterns that have been improperly installed have drinking water advisories from their installation date (Baird et al., 2013). The most common illnesses from drinking water issues are gastrointestinal with direct costs for medication and visits to health care professionals and indirect costs due to loss of work time and travel to health services. Henson's (2008) study on the direct and indirect cost of gastrointestinal illness in a British Columbia community found these costs to be $130 per capita annually. This value is conservative given that it is estimated that only 5% of gastrointestinal illnesses are reported and treated (Reynolds et al., 2008). However, contamination, and therefore related illness, is 2.5 times more likely on First Nations than other Canadian communities (Patrick, 2010). Further, there are other water-related issues such as skin rashes that are not considered (Plummer et al., 2011). Currently, we tripled the costs to $390 per capita annually based on Henson's study community to a Saskatchewan First Nation to better account for the increased frequency of contamination, other types of physical and psychological illness, and remoteness of these communities. This initial increase is arguably subjective in nature needing further validation, however, serves as a reasonable first approximation based on the costs provided by Henson (2008) and the higher risk provided by Patrick (2010).

Other costs added to the funding formula are the operation and maintenance of water delivery trucks and the roads impacted by the heavy trucks. From the CRM, the purchase of a new water delivery truck is approximately $160,000 and the annual funds provided for maintenance is $1,000 per cistern, based on the Capital Asset Inventory System from INAC. Hauling water is a burden on the operation and maintenance capacity of the community requiring about one truck for every 50 cisterns. These trucks are prone to breaking down as they are under heavy demand leaving the community to ration water when they are unavailable and/or or to pay for water from other sources (e.g., bottled water). The impact that these vehicles have travelling daily on gravel roads can increase the road maintenance cost for a community as well as decrease the life of the roads. Saskatchewan Ministry of Highways (2013) suggests compensation of $82.26/km for hauling in the summer and $41.13/km hauling in the winter to municipalities for heavy trucks their impact on rural roads. These values were used in the updated cost formula to account for the impact of the water delivery trucks on community roads.

3.3.2 Application to a Sample Community

As a case study, a comparison was made using the CRM for centralized (Table 3.2) and decentralized (Table 3.3) distribution using the values for a community project of approximately 100 homes and 500 people. The quantities used for these calculations include information from a project brief of a low-pressure water distribution system that was completed on a First Nation in Saskatchewan in 2011 (Consultant A, 2012). This project serviced 100 homes with density typical to rural residences on First Nations. This simple cost estimate does not include all project expenses but is limited to what the CRM has defined. However, we assumed that components absent from a more complete estimate would be similar in value to what would be absent from a decentralized project. Table 3.2 shows an initial capital cost of approximately $35,000 per home ($3.5 million total) which is three and a half times the amount ($10,000) that is typically allocated for water infrastructure projects.

Table 3.2: Application of CRM to Calculate Capital Cost of an Example Centralized Distribution System

Item		Units	Quantity	Unit Cost ($)	Total ($)
Installed Pipe	25mm	m	1,040	57	59,280
	38mm	m	18,300	69	1,262,700
	50mm	m	10,100	80	808,000
	75mm	m	2,700	100	270,000
	100mm	m	8,700	118	1,026,600
Isolation Valves	38mm	ea.	9	853	7,677
	50mm	ea.	11	853	9,383
	75mm	ea.	2	853	1,706
	100mm	ea.	6	853	5,118
Curbstops		ea.	100	278	27,800
Air release valves		ea.	6	5,600	33,600
				Total	3,511,864

In Table 3.3 the total capital cost is in close agreement ($13,648) with the typical allocation of $10,000 per home considered by INAC. However, this price could vary by community for the size of cistern and number of water delivery trucks.

Table 3.3: Application of CRM to Calculate Capital Cost of an Example Decentralized System

Item	Units	Quantity	Unit Cost ($)	Total ($)
Cistern (4500L)	ea.	100	5460	546,000
Housing Connection	ea.	100	5000	500,000
Water Delivery Truck	ea.	2	159,420	318,840
			Total	1,364,840

In addition to the initial capital cost of a decentralized system shown in Table 3.3, other annual costs were added to reflect the true cost of the system to the community (Table 3.4). Operation and maintenance values do not include routine maintenance of cisterns. The CAIS does not currently provide any operation and maintenance funding to low pressure distribution systems so for equal comparison it was omitted from decentralized systems as well. The amount of funding allocated for operation and maintenance of water delivery trucks is dependent on the number of cisterns and not the number of delivery trucks. This funding includes operator wages, fuel, and maintenance.

Table 3.4: Extra Annual Costs Associated with Decentralized System

Item	Units	Quantity	Unit Cost ($)	Total ($)
Cost of Illness	per capita	500	457	228, 500
Vehicle Maintenance	per cistern	100	1,000	100,000
Road Maintenance (summer)	km	1825	88	160,600
Road Maintenance (winter)	km	1825	44	80,300
			Total	569,400

Overall, the capital cost of a centralized system is $3.51 million and the capital cost of a decentralized system is $1.36 million. Starting from the capital costs, the annual costs of operation and maintenance can be added to each system over time to more accurately show the infrastructure costs over the 20 year lifetime (Fig. 3.3). The extra annual cost of a decentralized system is $569,400 with the largest portion ($240,900) attributed to the maintenance of roads which is already an issue for many communities. However, the cost of illness is also significant at $228,500 /year. Overall, the greater capital cost of a centralized system is justified in a short time at roughly four years (point of intersection of the systems in Fig. 3.3).

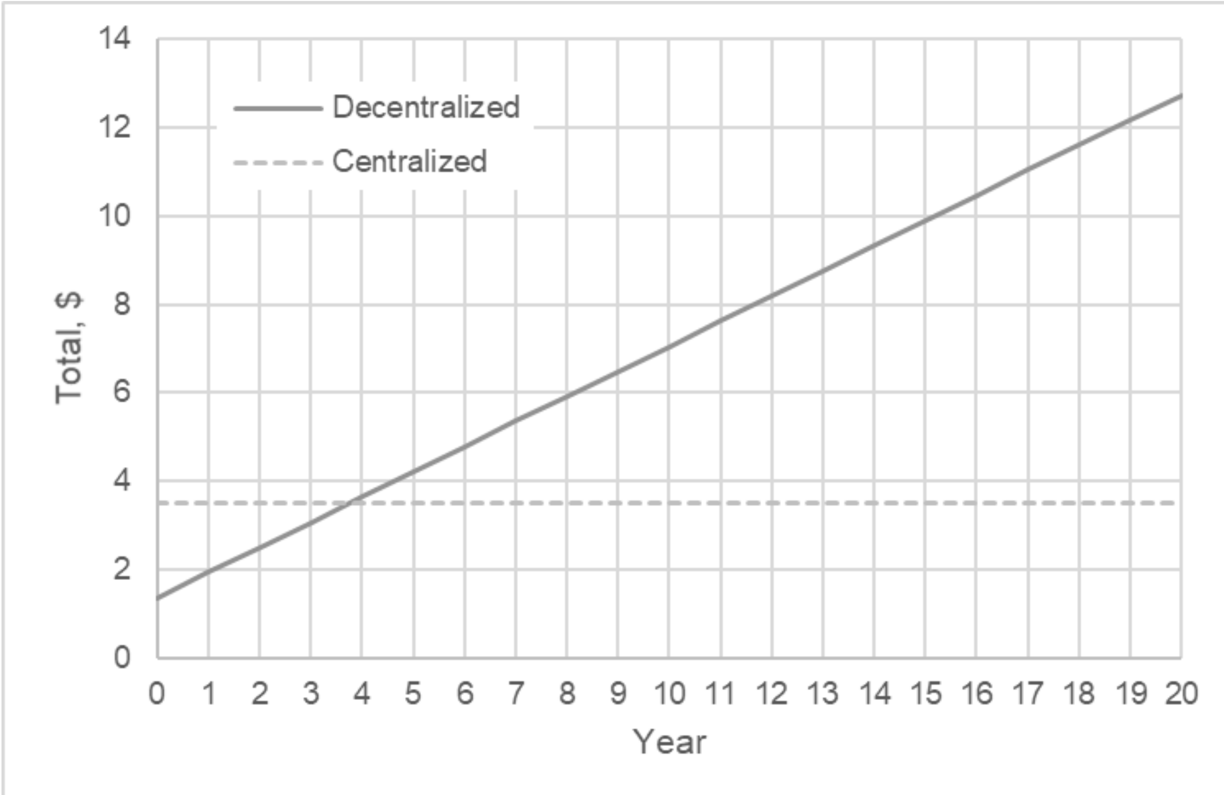


Figure 3.3: Annual Cost of Centralized and Decentralized Distribution (Values in Millions)

3.3.3 Comparison of Common Values

Common values for construction methods and materials used in water infrastructure projects were compared to see if there was any association or consistency in their determination. The sources that were compared were: INAC's Cost Reference Manual (2005), a completed rural centralized distribution project (2012), a feasibility study for centralized distribution (2017), and a bid analysis of three contractor's bids on a water infrastructure project (2011).

Table 3.5: Comparison of Values of Common Materials and Methods from Various Industry Sources

Item	Unit	2018 Value (CAD/unit)				
		INAC CRM	Community Project	Consultant	Contractor High	Contractor Low
Trench	m	*	33	96	196	95
Plough	m	*	11	30	N/A	N/A
25mm Pipe**	m	57	34	102	230	112
50mm Pipe**	m	80	35	103	N/A	N/A
75mm Pipe**	m	100	42	106	N/A	N/A
Gate Valve	ea.	852	330	N/A	N/A	N/A

* CRM includes only the cost of installed pipe and does not specify by which method

** Values for piping include the cost of installation

Clearly, general comparisons for each metric indicate no strong association between values for sources. The highest overall values were from contractors but the three contractor bids analyzed varied significantly. The CRM values were lower than the consultant and contractor bids indicating their inaccuracy given these values should align with actual costs. Interestingly, the lowest values were for the community infrastructure project that indicates the possibility of providing a centralized system for less than the CRM or an engineering consultant estimated costs. This lower price appears to be due to a source of inexpensive material that limited costs for the specific project. The consultant's feasibility study relates to the least expensive contractor. However, it is acknowledged that values for water infrastructure projects vary dependent on economic, geographic, political, and social factors making it difficult to generalize for projects on a national level and requires unique examination for every project.

3.4 Conclusions

Overall, it was determined that the INAC Capital Facilities Management Plan and CRM inadequately determines the cost of water infrastructure in Saskatchewan (and likely throughout Canada). The fundamental flaw with CRM is indexing all parameters to the urban Toronto example. Altus Group provides a construction cost index every year and is considered to be an industry standard (Altus Group, 2017). Using the values from this report and looking at data from Statistics Canada, it is shown that the cost of labour and materials for new construction varies year to year and by geography. Clearly, there is no simple, linear method to relate values from one city to another year by year as is done with the CRM. In general, the determination of index values from the CRM is neither referenced or justified and appears arbitrary lacking these details. Additionally, the multipliers are not justified for use year-over-year and, even if justified, the CRM is out-of-date with the most recent revision done over a decade ago in 2005.

In general, there is insufficient funding for both capital projects and ongoing operation and maintenance of water systems on First Nations. Trucked water and household cisterns are the lowest cost based on capital but these systems pose a greater impact to community health and infrastructure in the years after installation. Estimating for only construction cost has failed to provide technical systems that succeed long term and is more costly long term based on the true costs presented here. The greater capital cost of a centralized system is justified considering the extra costs from failing decentralized systems and that fact that extra capital costs are recovered within approximately 4 years. The benefits to human health and ensuring safe drinking water for a community is worth the extra investment on its own but this research has found it economically justified as well.

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Chapter 4: Discussion and Recommendations for Future Work

4.1 Discussion and Conclusions

The research conducted in my thesis arose from concerns around drinking water as presented by First Nation Communities in Saskatchewan. It was important that these concerns were addressed adequately in research as well as providing tangible benefits to the communities. With funding from the RBC Bluewater Project, community visits were conducted to gain valuable insight into water-related issues and priorities. Water based scientific presentations and demonstrations were conducted with elementary and high school students to provide the communities with something valuable in return for their time with the research team. Community members expressed a dissatisfaction with previous research and industry projects failing to properly engage the community and provide anything valuable in return for their time and information. It is important that research is conducted in this symbiotic manner so that trust and relationship is built which will be valuable for partnerships going forward.

There is a trend for design processes to be more inclusive of all stakeholders. It has been shown in the literature that stakeholders are beginning to acknowledge that projects would be more successful having the input and inclusion of the community that they are designed for. First Nations facing unique challenges in access to safe drinking water would be definite candidates to benefit from this practice having two worldviews come together on a single project. This design process however is likely more expensive and time-consuming making it potentially difficult to implement in communities that have rigid funding frameworks for infrastructure projects, such as First Nations. However, the potential improved quality of the resulting design and the potential reduced life cycle cost of the project may ultimately result in a less expensive project than current conventional methods.

The scoping review in Chapter 2 was performed to determine what literature exists and where research efforts could be focussed to better facilitate the growth of this trend towards co-design in water infrastructure projects. The review considered 1,551 articles and was narrowed down to just 13 articles that included co-design and water infrastructure search terms (or their synonyms). The preference was for Canadian examples, but the selection was expanded to include articles worldwide given the lack of available articles. It was noted that Canadian projects have not progressed further than consultation in most cases. The results in Chapter 2 found little definition of a term for ‘co-design’ and no procedure for an effective co-designed project. It would be difficult for industry to undertake a community-based design project because of the lack of definition in co-design as a term, let alone as a process in and of itself. The literature needs to be expanded to provide a clear pathway to perform inclusive design procedures. This would include an agreed upon definition of co-design that had a specified minimum level of inclusion. This requires a shift in education for professionals, a mindset change for the professional industry, and the adoption of other worldviews and understanding of social contexts.

Through the RBC visits, interviews and discussions, a concern perpetuated with the use of household cisterns and trucked water delivery. Communities find that cisterns are prone to contamination due to improper installation, contaminants entering during the filling of the water truck at the water treatment plant or filling the cistern at the house. The preference for communities is to have a centralized piped network that reduces likelihood for contamination and does not limit quantity. The constraint on the transition from decentralized to a centralized system is the larger capital expense of the infrastructure for dispersed housing models and the social and cultural change impacts of urban subdivision style housing implemented to accommodate gravity sewer systems. Funding is supplied by the federal government the lowest cost option appears to be the norm with no regard for life cycle costing or social costs. This lowest cost option for water infrastructure means cisterns at each home and a trucked delivery for any home not located in an urban type subdivision. However, this funding framework focuses too simply on the capital expense and does not address other indirect costs of these water systems. The results in Chapter 3 found that a centralized system is feasible when the funding framework is expanded to include health cost, loss of road life, and increased road maintenance from hauling. The communities want piped water distribution and the benefit to human health justifies the greater expense on its own, but this research found that it is economically justified as well.

4.2 Engineering Significance

The research in this thesis aimed to translate issues voiced by communities into tangible research outcomes. Frustrations were expressed with the lack of involvement in the processes of past projects while still being left with concerns about the quality of drinking water. The lack of community consultation and involvement in the process of water infrastructure projects is causing a failure in the resulting systems. The engineering community needs to adopt a more collaborative approach to address cultural and spiritual factors that influence the water system, particularly in First Nations communities. The review of current literature and infrastructure projects in Chapter 2 shows that more work has to be done to define what this type of collaborative and inclusive process would look like. This process would require more funding initially but could result in longer life of infrastructure, better community health, and savings long-term. Social elements like this can be quantified and considered as part of design alternatives. This will result in systems that are more effective by addressing all factors that could influence the system rather than just technical factors. Greater consultation, collaboration, and combination of worldviews will help engineers provide communities with solutions that address technical, environmental, and social priorities.

4.3 Future Work

- A well-defined process for community consultation and implementation of cultural and societal values in design should be established. This will help to inform professionals who are interested in following this approach. This requires a common definition of co-design to create the same level of involvement.
- A case study with a well-defined process applied would help illustrate the benefits and challenges for co-design. A series of case studies would help to influence regulation and policies if it is shown to be a successful process.
- There is anecdotal claim that the transition from a decentralized system to a centralized system improves water quality and human health. The water quality of a water system undergoing this transition could be tested throughout the process to quantify the change, if any.
- Currently, centralized systems that qualify for funding result in housing layouts typical to urban subdivisions. There is anecdotal evidence that these layouts are not preferred and are causing social issues. There is a need for the development of a design process that reflects social and cultural priorities in design of water infrastructure.
- It is shown that considering variables beyond capital investment and direct operation and maintenance is a more complete approach to considering alternatives. These additional

variables could include cost of impact to health and operation and maintenance costs of periphery infrastructure indirectly impacted. These extra variables can be better quantified to be applied consistently on design projects.

- The application of an expanded approach for considering funding elements on an actual design process would test its validity. A case study would be beneficial to quantify real examples of different variables. This would help set a useful precedent to aid in planning and funding of other projects.
- There needs to be flexibility in federal guidelines and policies so that co-design processes for water infrastructure on Indigenous lands are supported. This would allow projects to be initiated with unique approaches creating a collection of references for other projects.

Appendix A: Water Treatment Officer Interview Questions

Background

1. Could you please tell me about your position? How long have you held this position and what does your position entail? What do you do in a day? Do you have a back-up operator? Are you also the wastewater plant operator?
2. Could you please tell me some of the history of the water treatment plant in the community? What kind of roadblocks did you encounter, if any (INAC)? What kind of assistance did you encounter? Did your band contribute financially to the initial build of the treatment plant? How would you describe the process of working with the contractor and INAC?

Drinking water treatment plant design, maintenance and function

3. What kind of drinking water treatment plant do you have? When was it built? Which classification is it? What kind of disinfection do you use? How many community members/buildings does it serve? Do you have any issues with the treatment plant? If so, what are they?
4. What kind of storage facilities are there for the treated water? Issues with storage?
5. How many community-wide boil water advisories/orders have you had in the last five years? What were the reasons?
6. Does your community have a Community-Based Water Team (CBWT)?

Distribution

7. What types of distribution are there (wells, piped, delivered water)? What is "tap" water to community members? Do they drink the water?
8. If people have cisterns, what methods are in place to ensure their safety and cleanliness? Is there a regularly maintained maintenance schedule?
9. If people have wells, what methods are in place to ensure their safety? How often are they tested? How are they maintained?
10. How many drinking water advisories (DWAs) have there been for cisterns in the past 3 months? Year?

11. How many DWAs have there been for wells in the past 3 months? Year? Are there long-term advisories on any wells?
12. How much water do people on cisterns get in a week? Do homes on cisterns run out of water? What happens – how do they get water?
13. What are the (three) main issues with the distribution systems?

Source water protection

14. Do you have a source water protection plan for the community? For the source water (well heads, surface water intake)? Why or why not? Have there been any roadblocks?
15. Have you worked with neighboring municipalities or conservation stakeholders to develop and implement local watershed and aquifer protection plans?

Management

16. Are individual homes monitored for water usage (metres)? Charged? How much do they pay?
17. Do you provide water to other neighboring communities/farms/acreages? How? Why?
18. Do you have a maintenance plan and performance monitoring programs in place? How do you identify and assess risk in the water treatment plant? Do you have methods to report incidents and risk in the treatment plant? I.e. record of items in need of repair and replacement? How are these risks corrected? How is this communicated to your Chief and Council? EHO? INAC?
19. What prevents you from properly maintaining your water treatment plant (technical, economic, personal, community)? What supports and opportunities are there to promote and improve successful drinking water management?
20. Do you have an Emergency Response Plan for drinking water?
21. Are Asset Conditioning Reporting System Inspections carried out? By whom? How often?
22. Are Annual Assessments carried out? By whom? How often?
23. What opportunities exist for WTPO in terms of education, your position, work environment, etc.)? What barriers exist for WTPO?

24. How many CEUs are you required to attain during the year? Do you attain them? Who pays for your travel and registration? Is the training sufficient/applicable to your position?
25. What type of training does the water delivery driver(s) have?
26. Please tell me who is involved in the decision-making and/or budget for the water treatment plant at the community level. PMT level? Sewage treatment plant? What are the barriers to decision-making? (Involvement, hierarchical system, etc.) What supports collaborative decision making at these levels?
    a. If you are involved, does your community have enough money to cover the costs of treatment and distribution? Why or why not (barriers and supports)?

Monitoring and reporting

27. Are these three required types of monitoring followed?
    a. Operational (daily and weekly tests of raw, treated and distributed waters)
        i. What type of testing is used? What do you test for?
        ii. How are these recorded?
        iii. Does anything impact your ability to maintain this schedule?
    b. Quality assurance and quality control (no less than 10% of samples sent to lab for comparison)
    c. Compliance and third-party monitoring
28. Are the water delivery trucks tested? For what? How often? How does the testing? How are these recorded?
29. Is there a community-based water monitor? How was s/he trained? Are there opportunities for further training? Who provides the funding? Has s/he gone for further training?
30. How often does the water monitor test the distribution system? Does anything impact her/his ability to do her/his job?
31. What type(s) of communication system(s) is set up on reserve in order to notify residents about the community drinking water supply? Specifically, what happens when there is a community-wide boil water advisory, etc.? Household cistern/well advisory?

32. What type of communication is there between the water treatment officers and the EHO? What type of communication system is there between other government representatives?
33. What happens when an elevation is found in the treated water at the treatment plant? What is the process to fix it? If issues have occurred in the past, how long did it take to get resolved? What were the reasons for the delay/expediency?
34. What happens when an elevation is found in the treatment in the distribution system? What is the process to fix it? If issues have occurred in the past, how long did it take to get resolved? What were the reasons for the delay/expediency?

Public involvement and awareness

35. Are community members informed about their source water, drinking water, wastewater? Why or why not? How? (It is recommended that the WTPO make a copy of recent Annual Inspection Report AND the annual summaries of water quality monitoring results available to the public)
36. Please tell me about how community members' concerns on drinking water and wastewater are communicated to you? To Chief and Council? What are the barriers/challenges? What opportunities exist?

Research, innovation, science and technology

37. Do you, or your community, take part in any research for drinking water/waste water? Do you "keep up" with innovations in water treatment? Do you engage in education beyond what's required for your position?
38. What opportunities exist for innovative/improved treatment plant design, maintenance and monitoring? What barriers exist for treatment plant design, maintenance and monitoring? Are there other distribution systems that you are interested in? (What are the opportunities for distribution?)

General

39. What do First Nations people need in order to supply safe drinking water to their communities? What do First Nations people need, with regard to different processes and capacity needs, to change current and future conditions of drinking/water regulation? For Canada's First Nations?

40. How do the challenges surrounding First Nations' drinking water impact the health of individuals in your community? Families in your community? The entire community? I.e. What are the health implications (heard, experienced)?
41. What would be your ideal community water system? Are there any plans for the future for the drinking water systems in your community?
42. What would be your ideal community wastewater system? Are there any plans for the future for the wastewater systems in your community?
43. What are some of the concerns that community members have for their drinking water? Waste water? In your opinion, are they justified?
44. What would you say Chief and Council could do to improve reliable drinking water availability in the community? The community?

Appendix B: Student Exercise Forms

Just how much does your water filter cost anyways ???

In this activity you will be further studying your best water filter and determining the economic impact of your filter.

Water Usage

Canadian water usage (each day) is the second highest in the world and is approximately **326 liters** per person or capita (L/capita). The population of Saskatchewan is approximately 1.1 million (capita). Use the space below to calculate how much water is needed for Saskatchewan per day**. (L)**

L (per day)

How many filters ??

Now let's figure out how many of your filters would be needed to supply water for Saskatchewan.

Trial 1 **Filtering Time (s) ____________** **Turbidity ________**	**Trial 2** **Filtering Time (s) _________** **Turbidity ________**
1) How many seconds in a day? **s** 2) How many times a day can your filter be used? **repetitions/filter** 3) How many liters of water can each filter process in one day (250mL./rep = 0.25L/rep)? **L/filter** 4) How many filters are needed for Saskatchewan? **filters**	1) How many seconds in a day? **s** 2) How many times a day can your filter be used? **repetitions/filter** 3) How many liters of water can each filter process in one day (250mL./rep = 0.25L/rep)? **L/filter** 4) How many filters are needed for Saskatchewan? **filters**

How much does one filter cost??

You only need to cost out the price of fine and coarse sand.

The price of materials is as follows:

Fine Sand - $0.50 / 250mL (60 mL per scoop)

Coarse Sand - $0.25 / 250mL (60 mL per scoop)

Use the table below:

Material	Trial 1		Trial 2	
	Amount of Material (# scoops * 60mL)	Price ($)	Amount of Material (# scoops * 60mL)	Price ($)
Fine Sand				
Coarse Sand				
Total Filter Cost:				

So, how much would it cost Saskatchewan to use your filter??

Use the table provided to determine how much it would cost the city to use your water filter to filter Saskatchewan's water.

Trial 1		Trial 2	
Price per filter ($)		Price per filter ($)	
# of filters need for Saskatchewan		# of filters need for Saskatchewan	
TOTAL COST ($)		TOTAL COST ($)	

Appendix C: Student Quotes from Post-It Exercise

"It is important"

"flooding"

"our body is made up of 60% water (?)."

"Water is life"

"lagoon smell"

"cost of bottled water"

"water is life #lit"

"air pollution. Is melted snow safe to drink?"

"Plant trees around lagoon. Absorb smell gases."

"need pipe distribution"

"pump needs repair"

"water is life"

"I think water is important"

"There are little particles tat float on the water which might cause sicknesses."

"Water means life to me!"

"Contaminate the lake. Boats. Sewage."

"It's dirty polluted dead fish contamination leeches."

"Polluted lakes. No good water in lakes. We can't drink tap water"

"Pipeline Spills"

"Cisterns need repairs"

"Clean water is life water is being wasted."

"Hardness. Skin sores."

"Clean water for swimming"

"Boil water advisories"

"#noDAPL Standing Rock"

"Water issues: sometimes it can be polluted, you can get rashes and different sicknesses, it kills some of the fish, farmers use fertilize(r)s to spray plants and it's kind of harmful"

“Water issues: pollution, boats, sewer getting dumped in the lake, pesticides”

“We can’t swim in our lakes, drink lake water, we can’t see the bottom”

“Water pollution: contamination, sewage waste, pesticides, chemicals, algae, blue algae”

“Pollution. Pesticides. Algae (motor boats).”

“Drink Water”

“I run out of water at my house. There is nine people in my house. I learn today how they chained the water filter. I have a clean beach in Pasqua”

“I drink my water from muscowpetung water treatment. I run out of water because we need it to drink water and cook with it. Sometimes we half to drink tap water we run out of water. We go to the beach is so sick you can get sick and scabs. They are gross stuff and dirty stuff in the beach. 7 people live in my house”

“I don’t like to drink my tap water. I drink from jug water I go get it from the Piapot water treatment. I learned today not to drink dirty water and other stuff.”

“I little bit like tap water sometimes it het me sick. But I healty for you because its plant water is kinda good.”

“I’ll swim in my own pool in then I’ll take a nice clean shower in I’ll drink the tap water in it taste like the plant water”

“The lake is dirty. I have to take a shower when I am done at the beach/lake.”

“You can drink our water and Woody helps everyone in our community. He cleans our water and he makes sure the water we drink is clean. And the water we drink is good for us. And what we use our water for is for drinking, shower, bath, washing dishes.”

“For food to boil water, to give to animals and our water comes from underground or on top of the ground and scientists do tests on the water and they make sure the water is clean. And you can also give some water to the children who don’t get all the water like we do and you can get your water from lakes, oceans. And we are lucky we have water on our land because if we didn’t have water we wouldn’t be able to love on the earth..”

Drawing depicting water being poisoned, “dead fish along the shore”, and “no more water”

“Water is life”

“Twas fun can we do it again soon? #blessed #noDAPL #waterislife!”

“Bill C-45(?) The 2013 bill to deregulate water. (Private Members Bill)”

“Water is very important since most of our bodies are made up of water. Without everything that has life wouldn’t survive. Stay hydrated.”

“Water is how we survive. If we don’t have it we’ll die.”

"Our water is important because the water is very low."

"H2O is life"

"Without clean water, there's no point living."

"Water is everything"

"Body needs water. Without water you get cramps (mucles). Dehydration. You can only go so long and must have water."

"Water is importatnt because your body is made of it. And it's something to drink."

"Water is healthy."

"Water is life"

"Water is a need for all live beings, it is vital for health, growth, and survival. Water is very sacarite and useful."

"ugly got water"

"Some issues we have in our community include that we have an boil water advisory, and some people have to haul water to their houses."

"Water is life. Water is baby jesus."

"I'm 80% of water so…"

"What does water mean to you and what are some of the issues in your community. I guess water issues: have here on the reserve are filtering and maybe even the warm water issue! We always run out of warm water, and we are a family of 9 in a house we live in."

"I drink water down the hill cause the tap will break and kind of dusty or probably something died down the tap. And its better than pop or sugary stuff. Water is not sugary at all so its better than pop or stuff probably slurpees. Or you will get cavities if you have to much and you might go to the dentist. I love slurpees and pop and pepsi."

"Pollution. Dead fish in the lake."

"Dumping in our lake. Our water plant breaking down what will we do"

"Dead fishes in the lake. Have to boil water to drink it. Dumping in the lake"

"I dranke water at home. I drink my water out of the tap. I go swimming in the pool after I take a shower"

"I can't drink from my tab because it is not clean to drink."

"everyday I get my drinking water from a jug because our sisterns have E.coli in them"

"I drink the tap water. I live in Piapot First Nation and sometimes I drink the water plant water sometimes. And sometimes I like to fish."

“I like swimming in the lake. I love water and its healthy and survive us and live. I like water so much and it good.”

“I don’t like the tap water. I like swimming clean water. I just drink clean water. We cant drink dirty water. I like to fish and eat the fish.”

“I like to fish in the river and I like to swim in the river we need water to survive and I don’t like tap water.”

“I don’t like tapwater.”

“I learn about water from payepot and were it comes from. I drink tap water.”

“That it is important to our bodies. Cant do launder. Don’t drink tap water. We use jugs.”

“I like to swim in the lake and have fun with my brothers and cousins but the lake is dirty but I like to drink water so I can run and play and walk and go for a drive so I can get..”

Appendix D: Presentation Slides from Classroom Visits

Before today, have you ever thought about **engineers** and what they do?

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Engineers apply science
and use creativity
to **solve problems**
and make society better

engineering.usask.ca

UNIVERSITY OF SASKATCHEWAN

College of Engineering Indigenous Peoples Initiatives

Being a professional
engineer means always
considering **safety, cost** and
impact on society

engineering.usask.ca

Engineers do their job so well, that they are **invisible** to the general population

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Imagine… a world without engineers would be a world without

Safe water to use (Environmental Engineers)
Cars to drive (Mechanical Engineers)
Electricity, electronics (Electrical Engineers)
Buildings, bridges and roads (Civil Engineers)

engineering.usask.ca

Engineering Design Process

i. Define the Problem
ii. Brainstorm Design Ideas
iii. Evaluate & Choose
iv. Design & Build
v. Communicate

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Benefits of Being an Engineer

i. Use your creativity
ii. Design things that matter
iii. Collaborate to solve problems
iv. $$
v. Job security and flexibility

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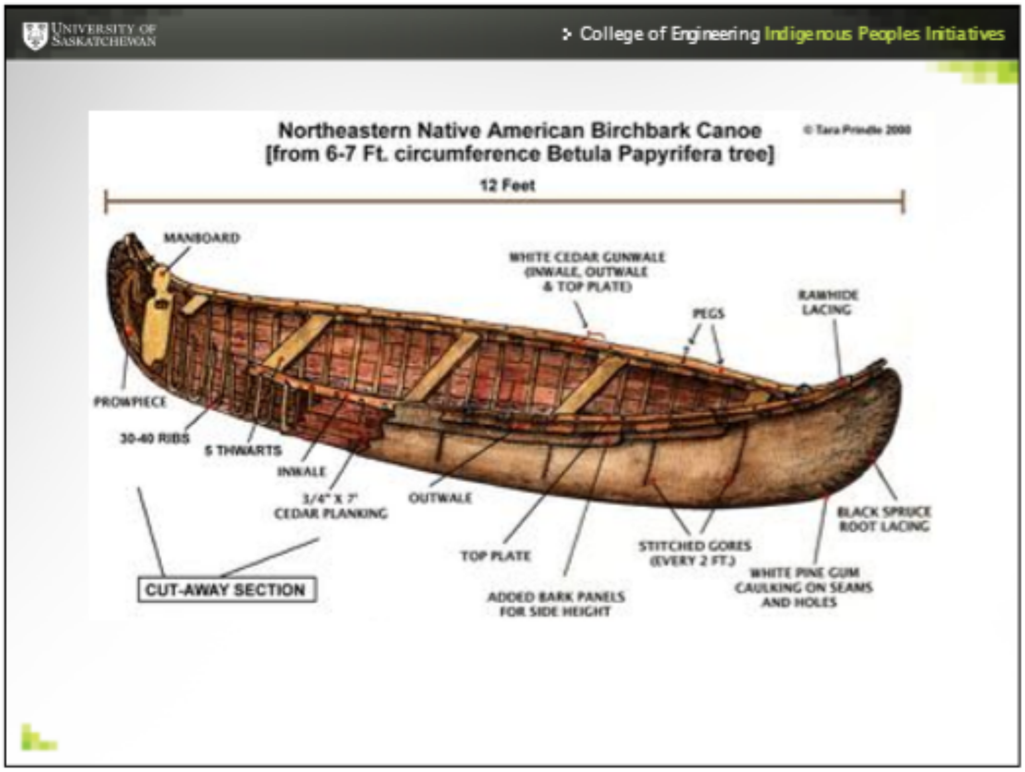
University of Saskatchewan
College of Engineering Indigenous Peoples Initiatives
Northeastern Native American Birchbark Canoe
[from 6-7 Ft. circumference Betula Papyrifera tree]
© Tara Prindle 2000
12 Feet
MANBOARD
WHITE CEDAR GUNWALE (INWALE, OUTWALE & TOP PLATE)
PEGS
RAWHIDE LACING
PROWPIECE
30-40 RIBS
5 THWARTS
INWALE
3/4" X 7' CEDAR PLANKING
OUTWALE
BLACK SPRUCE ROOT LACING
TOP PLATE
STITCHED GORES (EVERY 2 FT.)
WHITE PINE GUM CAULKING ON SEAMS AND HOLES
CUT-AWAY SECTION
ADDED BARK PANELS FOR SIDE HEIGHT


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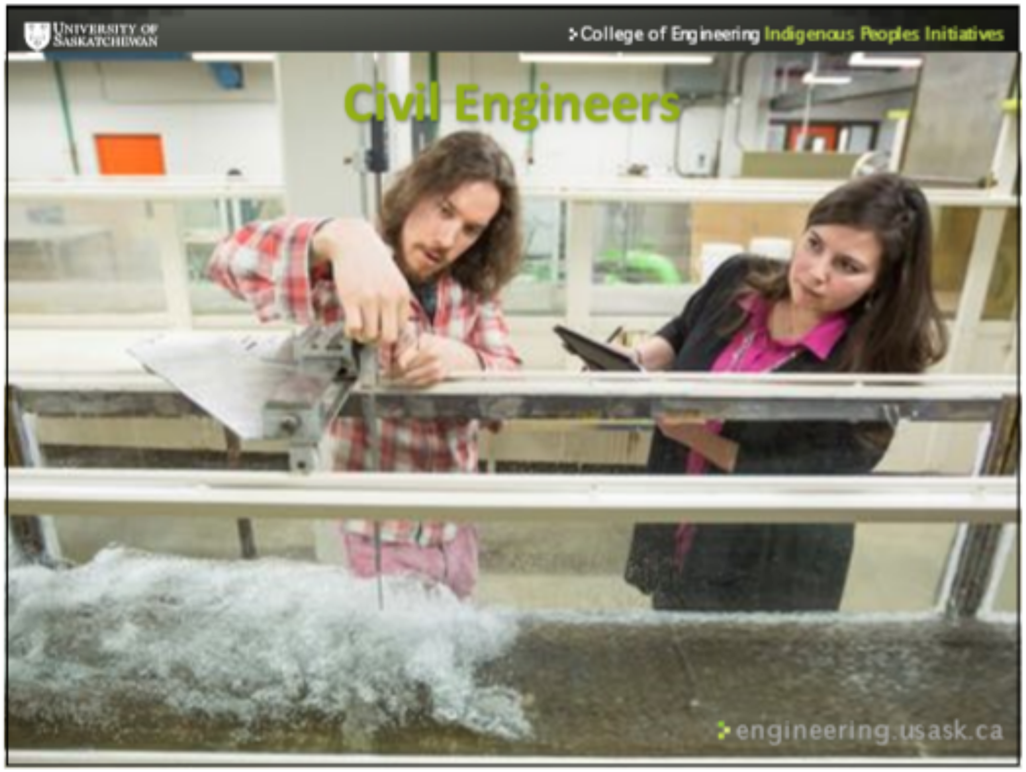
Chemical Engineers
engineering.usask.ca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Civil Engineers
engineering.usask.ca


University of Saskatchewan
College of Engineering Indigenous Peoples Initiatives
Environmental Engineers
http://www.src.sk.ca/careers/pages/aboriginal-mentorship-program.aspx

Engineering Design Challenge

i. Problem: A road is flooded out and you need to get across
ii. Brainstorm design ideas
iii. Evaluate the ideas and choose one
iv. Design, build and test the design
v. Communicate the design and test results to your classmates

U of S College of Engineering
Admission Requirements

Grade 12 level subjects or equivalents:

- Chemistry*
- Physics*
- Pre-calculus mathematics*
- Calculus *

*Apart from meeting the admission average for the college, minimum of 70% required in each of the indicated courses.

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University of Saskatchewan
College of Engineering

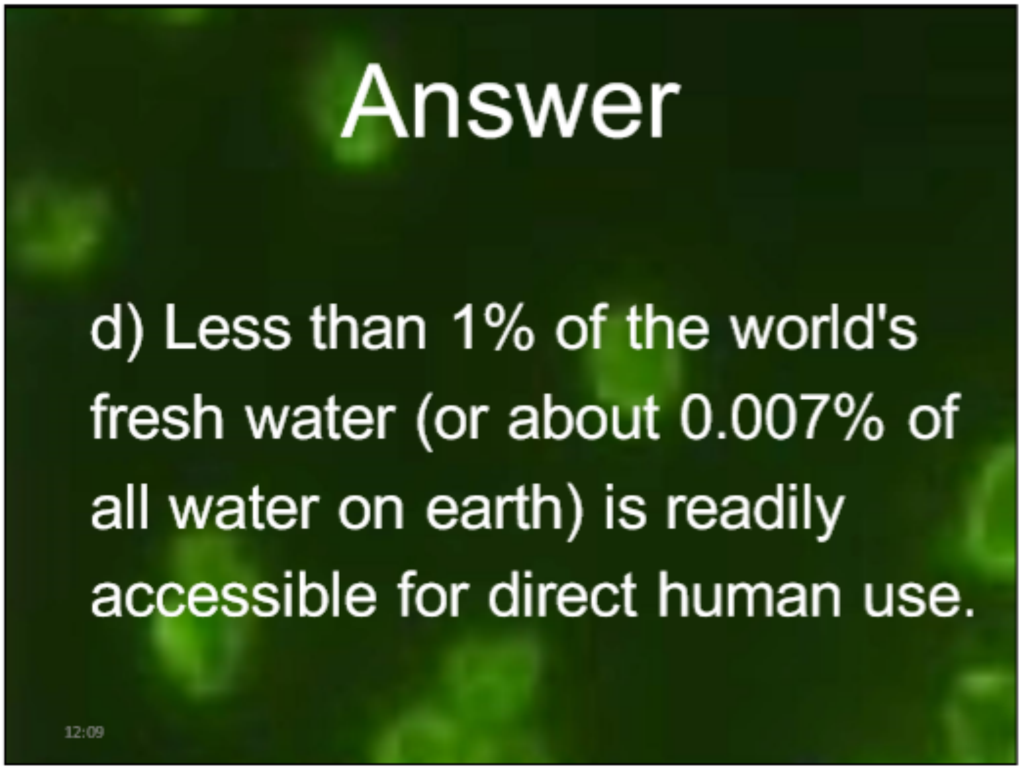
For more information on the Indigenous Peoples Initiatives please contact:

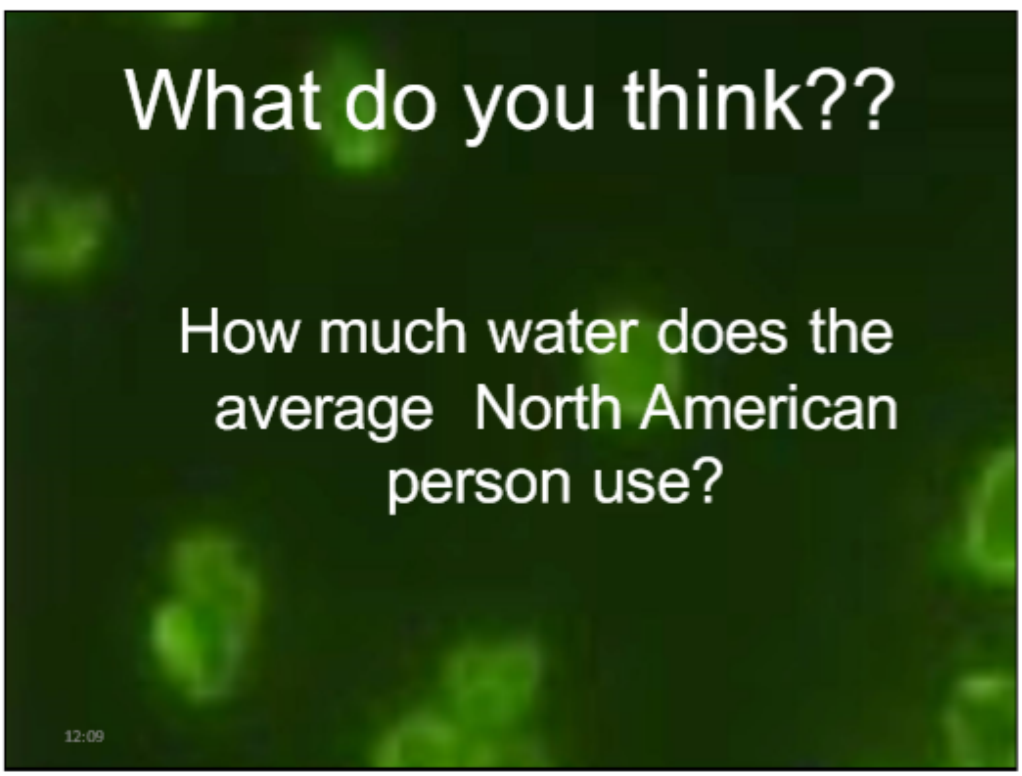
Matthew Dunn
Indigenous Peoples Initiatives Coordinator
Room 2A07, College of Engineering

(306) 966-4910
indigenous.engineering@usask.ca


RBC Blue Water Project
12:09


What do you think?
How much of the world's freshwater is readily available for human use?
a) 23%
b) 8%
c) 2%
d) Less than 1%
12:09


Answer
d) Less than 1% of the world's fresh water (or about 0.007% of all water on earth) is readily accessible for direct human use.
12:09


What do you think??
How much water does the average North American person use?
12:09

Answer:

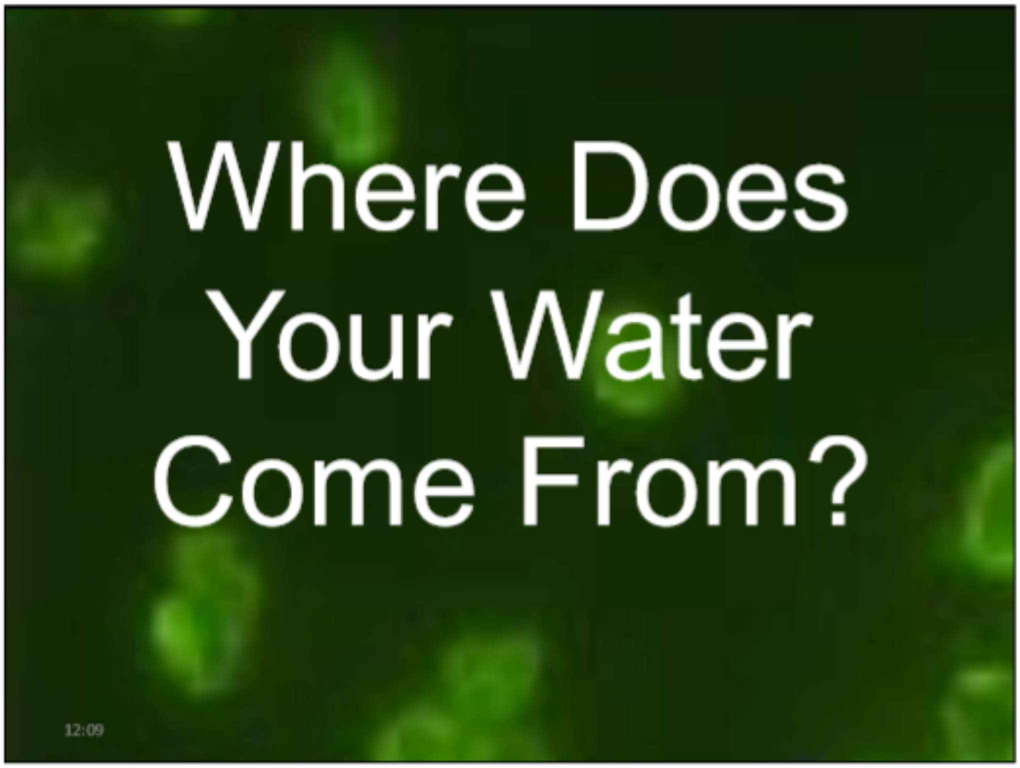
The average North American individual uses 440 to 775 litres of water at home each day.

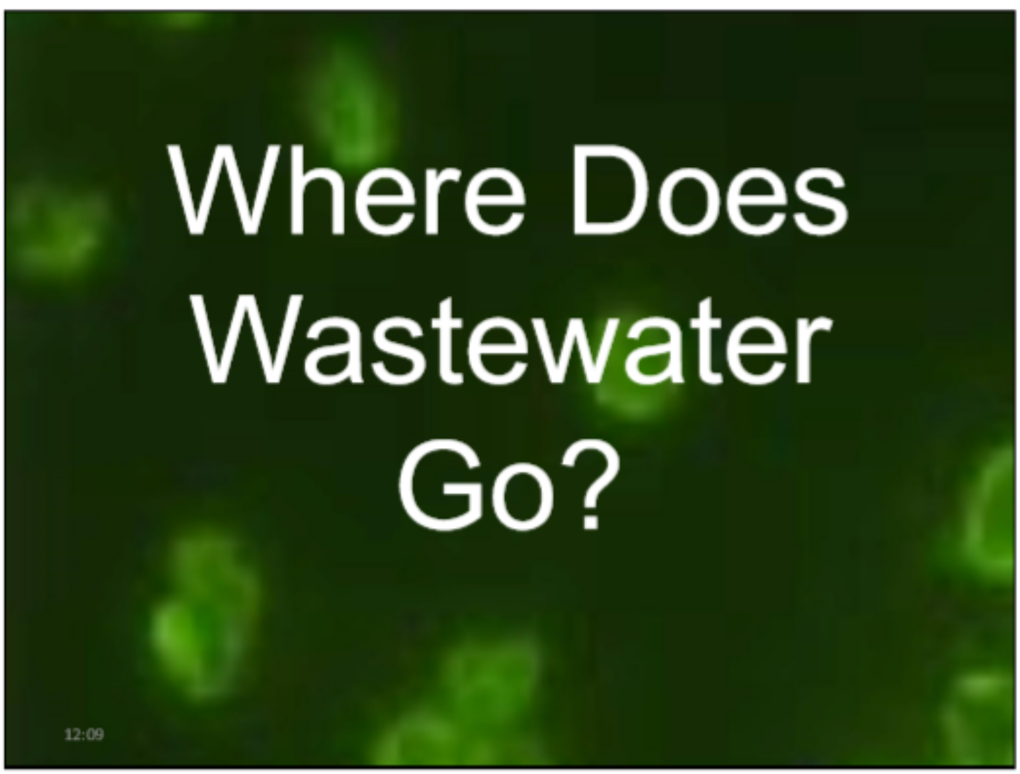
12:09

Why So Much??

- Toilets - 6 to 13L /flush
- Showers – 14L / minute
- Baths – 164L for a full bath
- Brushing Teeth/Washing hands – 14L / minute faucet is on
- Dishwasher – 14L / minute
- Laundry – 200 L / load

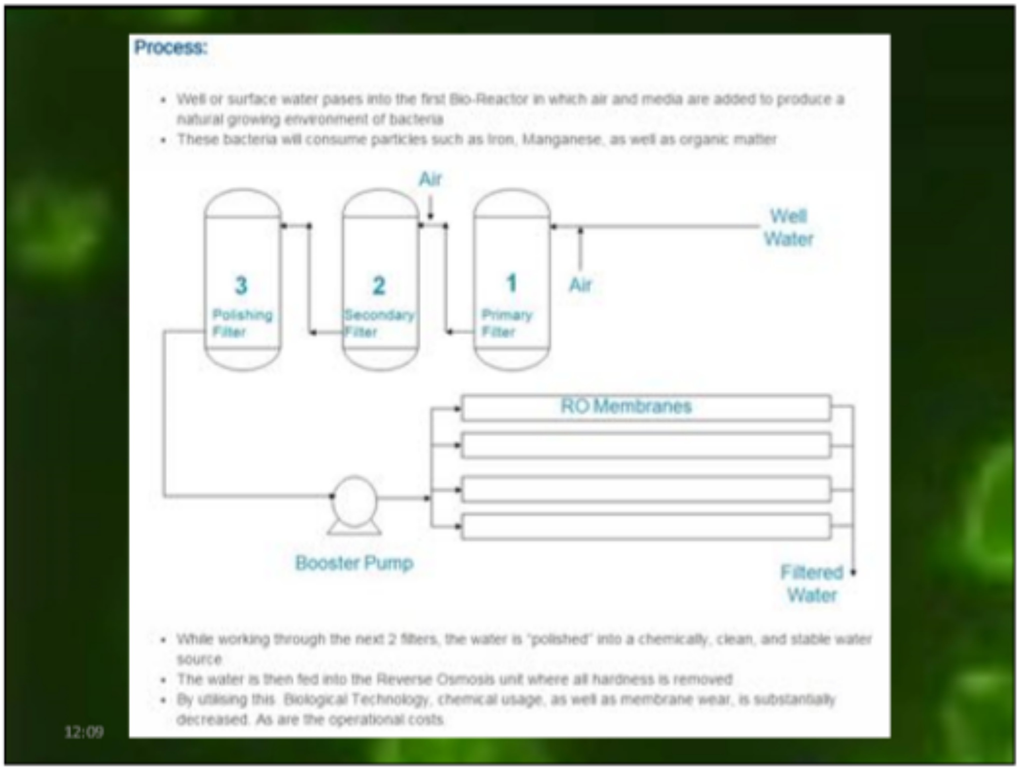
12:09

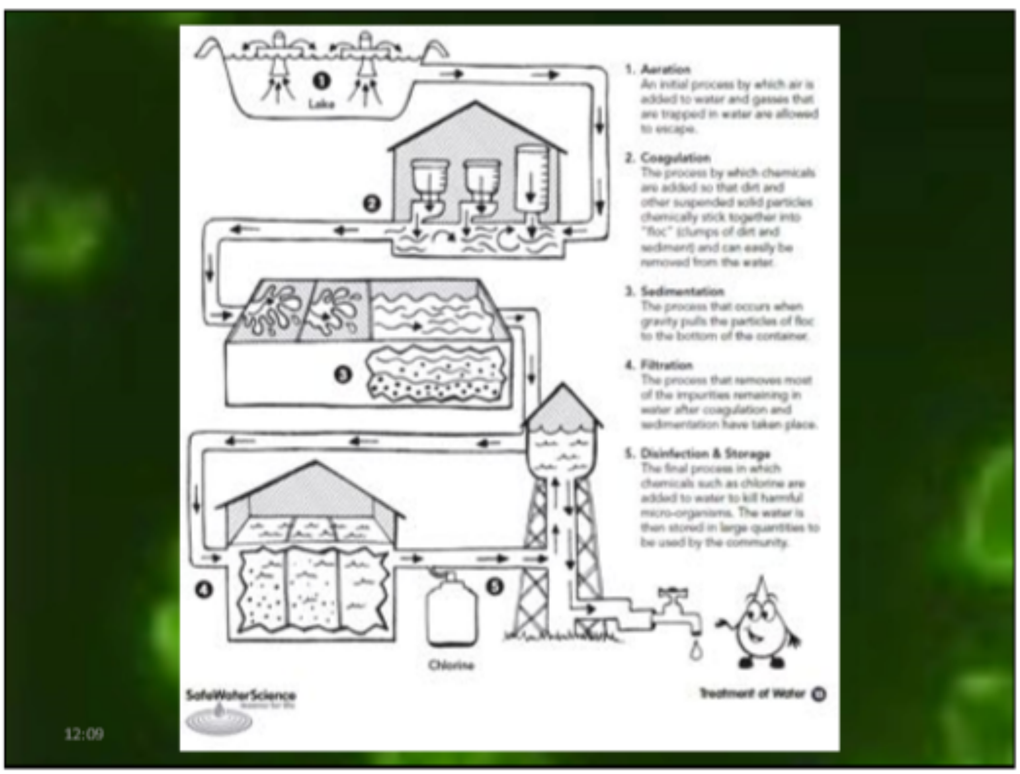

Where Does
Your Water
Come From?
12:09


Where Does
Wastewater
Go?
12:09


How Do We
Get Safe
Drinking Water?
12:09


Water
Treatment &
Distribution
12:09


Process:
Well or surface water pases into the first Bio-Reactor in which air and media are added to produce a natural growing environment of bacteria
These bacteria will consume particles such as Iron, Manganese, as well as organic matter
Air
Well Water
Air
3 Polishing Filter
2 Secondary Filter
1 Primary Filter
RO Membranes
Booster Pump
Filtered Water
While working through the next 2 filters, the water is "polished" into a chemically, clean, and stable water source
The water is then fed into the Reverse Osmosis unit where all hardness is removed
By utilising this Biological Technology, chemical usage, as well as membrane wear, is substantially decreased. As are the operational costs
12:09


Lake
Chlorine
1. Aeration
An initial process by which air is added to water and gasses that are trapped in water are allowed to escape.
2. Coagulation
The process by which chemicals are added so that dirt and other suspended solid particles chemically stick together into "floc" (clumps of dirt and sediment) and can easily be removed from the water.
3. Sedimentation
The process that occurs when gravity pulls the particles of floc to the bottom of the container.
4. Filtration
The process that removes most of the impurities remaining in water after coagulation and sedimentation have taken place.
5. Disinfection & Storage
The final process in which chemicals such as chlorine are added to water to kill harmful micro-organisms. The water is then stored in large quantities to be used by the community.
SafeWaterScience
Treatment of Water
12:09

A Water Treatment Plant

How do different types of engineers work together in a water treatment plant??

12:09

A Water Treatment Plant

Environmental Engineers

- Designs the process to treat the water.
- Example: What chemicals are used and in what quantity?

12:09

A Water Treatment Plant

Civil Engineers

- Help design the building and other structures such as the holding tanks
- Example: How thick do the walls of a holding tanks have to be so they don't leak?

12:09

A Water Treatment Plant

Mechanical Engineers

- Design methods to move water from point to point within the water treatment plant as well as to the public.
- Example: How big of a pump do we need to get water from the treatment plant to the homes?

12:09

A Water Treatment Plant

Electrical Engineers

- Ensures the water treatment plant has appropriate power to run, provides controls for machinery etc..
- Example: Write programs to monitor the machines, making sure they are functioning properly.

12:09

Today…

You are an Environmental engineer and your task is to create a water filter that is both effective and economical.

12:09